

Masters Program in **Geospatial Technologies**



A Prospective Geoinformatic Approach to Indoor Navigation for Unmanned Air System (UAS) by use of Quick Response (QR) codes

Emilio Troncho Jordán

Dissertation submitted in partial fulfilment of the requirements
for the Degree of *Master of Science in Geospatial Technologies*

A Prospective Geoinformatics Approach to Indoor Navigation for Unmanned Air System (UAS) by use of Quick Response (QR) codes

By

Emilio Troncho Jordán

Dissertation supervised by

Ignacio Guerrero, Ph.D

Institute of New Imaging Technologies (INIT), Universitat Jaume I, Castellón, Spain

Cosupervised by

Torsten Prinz, Ph.D

Westfälische Wilhelms-Universität (WWU), Münster, Germany

and

Roberto Henriques, Ph.D

NOVA Information Management School (NOVA IMS), Universidade Nova de

Lisboa, Lisbon, Portugal.

February 2016, Castellon

ACKNOWLEDGMENTS

I would like to thank Professor Dr. Ignacio Guerrero, for being my supervisor, for all the help he provided and for showing me the remote sensing world. Besides, I would like to thank my Co-supervisors, Professor Dr. Torsten Prinz, for all the help and for providing me with the first introduction in the UAS world and Professor Dr. Roberto Henriques for his contribution.

Thanks also to all my student partners, a special mention to Andrea for their support, help and friendship, it's been a pleasure to share this journey with them and to help each other.

Special thanks to my parents, family and friends for making this possible.

“Me lo contaron y lo olvidé. Lo vi y lo entendí. Lo hice y lo aprendí.” (Confucio, 551-479 a. C.)

A Prospective Geoinformatics Approach to Indoor Navigation for Unmanned Air System (UAS) by use of Quick Response (QR) codes

ABSTRACT

This research study explores a navigation system for autonomous indoor flight of Unmanned Aircraft Systems (UAS) dead reckoning with Inertial Navigation System (INS) and the use of low cost artificial landmarks, Quick Response (QR) codes placed on the floor and allows for fully autonomous flight with all computation done onboard UAS on embedded hardware. We provide a detailed description of all system components and application. Additionally, we show how the system is integrated with a commercial UAS and provide results of experimental autonomous flight tests. To our knowledge, this system is one of the first to allow for complete closed-loop control and goal-driven navigation of a UAS in an indoor setting without requiring connection to any external infrastructures.

A Prospective Geoinformatics Approach to Indoor Navigation for Unmanned Air System (UAS) by use of Quick Response (QR) codes

ABSTRACT (Spanish)

Este estudio de investigación explora un sistema de navegación para el vuelo interior autónomo de Sistemas Aéreos No Tripulados (UAS) a estima, utilizando para ello el Sistema de Navegación Inercial (INS) y el uso de referencias artificiales de bajo coste, códigos Quick Response (QR) colocados en el terreno y permitiendo el vuelo totalmente autónomo. Para ello se utilizaran sistemas embebidos a bordo del UAS. Proporcionamos una descripción detallada de todos los componentes del sistema y desarrollo de la aplicación. Además, se muestra cómo el sistema está integrado con un UAS comercial y se proporcionan resultados de las pruebas de vuelo autónomos experimentales. Desde nuestro conocimiento, este sistema es uno de los primero en realizar un vuelo autónomo de un UAS en bucle cerrado sin la ayuda de señales externas.

KEYWORDS

Unmanned Aircraft System

Indoor Navigation

QR codes

Inertial Navigation System

KEYWORDS (Spanish)

Sistema Aéreo No Tripulado

Navegación en Interior de Edificaciones

Códigos QR

Sistemas de Navegación Inercial

ACRONYMS

AESA – Agencia Estatal de Seguridad Aérea
API – Application Programming Interface
AoA – Angle of arrival
EASA – European Aviation Safety Agency
GIS – Geographical Information Systems
GNSS – Global Navigation Satellite Systems
GPS – Global Positioning System
ICAO – International Civil Aviation Organization
IGS – Inertial Guidance System
INS – Inertial Navigation System
IMU – Inertial Measurement Unit
IR – Infrared
LIDAR – Laser Imaging Detection and Ranging
LoS – Line of Sight
QR – Quick Response
RF – Radio Frequency
RPAS – Remotely Piloted Aircraft Systems
RSS – Received Strength Signals
RSSI – Received Signal Strength Indicator
SAR – Search and Rescue
SOP – Signals of opportunity
SDK – Software Development Kit
TDoA – Time Difference of Arrival
ToF – Time of Flight
UAV – Unmanned Aerial Vehicle
UAS – Unmanned Air System
US – Ultrasound
UWB – Ultra-wideband radio

INDEX OF THE TEXT

	Pag.
ACKNOWLEDGMENTS	ii
ABSTRACT.....	iii
ABSTRACT.....	iv
KEYWORDS	v
KEYWORDS.....	v
ACRONYMS.....	vi
INDEX OF TABLES.....	ix
INDEX OF FIGURES	x
1. INTRODUCTION	1
1.1 Introduction.....	1
1.2 Motivation.....	4
1.3 Aims and Objective.....	6
1.4 Challenges.....	7
1.5 Regulations	7
2. OVERVIEW	8
2.1 Indoor Navigation	8
2.2 Indoor Localization Techniques	8
2.2.1 Technologies Based on Signals of Opportunity (SOP).....	8
2.2.1.1 Wi-Fi and Bluetooth	8
2.2.2 Technologies Based on Pre-deployed Infrastructure	9
2.2.2.1 Radio Frequency Identification (RFID).....	9
2.2.2.2 Ultrasound.....	10
2.2.2.3 Infrared (IR).....	10
2.2.2.4 Ultra-wideband Radio (UWB).....	11
2.2.3 Others Technologies	11
2.2.3.1 Inertial Navigation System (INS)	11
2.3 Preliminary Theory	12
2.3.1 Inertial Sensors and Heading	12
2.3.1.1 Electronic Compass	13
2.3.1.2 Accelerometer.....	14
2.3.1.3 Gyroscope.....	15
2.3.1.4 Inertial Measurement Unit (IMU).....	17
2.3.2 Quick Response (QR) Code.....	18
2.3.3 Introduction to Unmanned Air System (UAS)	
Quadcopter.....	19

3. AR.DRONE 2.0.....	24
3.1 Hardware AR.Drone 2.0	26
3.1.1 Electronic Features.....	26
3.1.2 HD Video Recording.....	26
3.1.3 Structure.....	27
3.1.4 Motor.....	27
3.2 Software AR.Drone 2.0.....	28
3.2.1 Architecture.....	28
3.2.2 SDK 2.0.1.....	29
4. INDOOR NAVIGATION SYSTEM IMPLEMENTATION.....	31
4.1 Onboard Hardware.....	31
4.1.1 Raspberry Pi Zero	31
4.2 Software Prerequisites	32
4.2.1 Linux.....	32
4.2.2 Node.js.....	32
4.2.3 Node ar-drone.....	33
4.2.4 Cairo.....	33
4.2.5 FFmpeg.....	33
4.2.6 Qrqr.....	33
4.3 Drone-browser.....	34
4.4 Codigo-Qr.es.....	34
4.5 Main application.....	35
4.5.1 Streaming Video	36
4.5.2 Navigation data	37
4.5.3 Node-ar-drone-pilot	39
4.5.4 Drone-pilot.js	40
5. TESTING AND RESULTS.....	43
5.1 Communication AR.Drone 2.0-Client	43
5.2 Running the Application node-ar-drone-pilot	44
5.3 Results.....	45
6. CONCLUSIONS AND FUTURE WORK.....	48
6.1 Conclusions.....	48
6.2 Future Work.....	49
BIBLIOGRAPHIC REFERENCES.....	51
ATTACHMENTS.....	56
A1. Navdata.....	56
A2. Magnetometer Data.....	57

INDEX OF TABLES

Table 1: Comparative summary positioning systems based on radio, ranked by technology, coverage and accuracy.....	12
Table 2: Structure of data from navdata, ranked by navdata name, type of variable, description, and unit of measurement.....	38
Table 3: Ideal parameters for the test obtained after different tests. In these tests, it was obtained an accuracy of 2 meters	47
Table A-1: Navdata packets obtained from the UAS in one flight.....	56
Table A-2: Magnetometer data obtained from the UAS in one flight.....	57

INDEX OF FIGURES

Figure 1: The Apollo spaceship (IMU) for navigation guidance and control to carry men to the Moon and back, that contains three gimbals, platform electronics, accelerometers and gyros [2]	2
Figure 2: Parrot AR.Drone2.0 used for developing this project [38].....	4
Figure 3: Global Hawk, NASA's unmanned aircraft system for high-altitude, long-duration Earth science missions [5].....	5
Figure 4: National and international aviation safety agencies, Agencia Estatal de Seguridad Aérea (AESA, Spain), European Aviation Safety Agency (EASA, Europe), European Organization for the Safety of Air Navigation (Eurocontrol, Europe) and International Civil Aviation Organization (ICAO, worldwide), agencies that regulate the activities of UAS [54][55][56][57]	7
Figure 5: 3-Axis Digital Compass HMC5883L used in AR.Drone 2.0 [43].....	13
Figure 6: Basic components of a mechanical accelerometer [30].....	14
Figure 7: MEMS accelerometer. Given its small size it is possible to integrate into many electronic devices [32].....	15
Figure 8: Basic diagram of the mechanical gyroscope. A mechanical device used to measure, maintain or change the orientation in space [30].....	16
Figure 9: MEMS gyroscope from STMicroelectronics. Given its small size it is possible to integrate into many electronic devices [32].....	17
Figure 10: IMU blocks diagram. Electronic device that measures and reports speed, orientation and gravitational forces of a device, using a combination of accelerometers and gyroscopes [31].....	17
Figure 11: QR code - takeoff (). Takeoff instructions encoded in QR code with codigo-qr [51].....	18
Figure 12: Three-dimensional reference system. A coordinate system is a set of Values and points that allow uniquely define the position of any point in space [37].....	19
Figure 13: Pitch, roll and yaw axis definition for an airplane [37].....	20
Figure 14: Cross structure of a quadcopter [38].....	20
Figure 15: Four rotors with the same power for climbing [38]	21
Figure 16: Roll movement [38].....	21
Figure 17: Pitch movement [38].....	22

Figure 18: Yaw movement [38]	22
Figure 19: Behavior of the quadcopters rotors for different movements, a) backward, b) forward, c) left roll, d) right roll, e) up, f) down, g) left yaw, h) right yaw [38].....	23
Figure 20: AR.Drone 2.0 (top and bottom view with indoor cover) [3].....	24
Figure 21: Pitch and roll movements [3]... ..	24
Figure 22: Rotation movement about its vertical axis [3].....	24
Figure 23: Elevation and descending movements [3].....	25
Figure 24: Electronic specifications and position in the structure of the AR.Drone 2.0 [43].....	28
Figure 25: Here is an overview of the layered architecture of a host application built upon the AR.Drone 2.0 SDK [41].....	29
Figure 26: Raspberry Pi Zero. Its size is ideal for this project because it can be installed inside the hull of the AR.Drone 2.0 [52].....	31
Figure 27: Software versions in Raspberry Pi.....	32
Figure 28: Ubuntu version installed in laptop.....	32
Figure 29: Node.js version installed	32
Figure 30: Installing ar-drone.....	33
Figure 31: Installing Cairo library	33
Figure 32: Installing FFmpeg.....	33
Figure 33: Manual control application execution for controlling AR.Drone 2.0	34
Figure 34: Manual control for AR.Drone 2.0. In case of problems with the autonomous flight application, we will take the control of the AR.Drone 2.0 by this application.....	34
Figure 35: Dialog box of Codigo-QR. Application to generate QR codes with the information that we insert it [51].....	34
Figure 36: Result of the instruction takeoff () in a QR code using Codigo-qr [51].....	35
Figure 37: Diagram of the architecture of the autonomous navigation system.	36
Figure 38: Front and bottom cameras in AR.Drone 2.0, cameras used to read QR codes and observe the environment	36

Figure 39: Communication Client-AR.Drone 2.0. Ports for exchanging information between client-AR.Drone 2.0, in this case, video stream and navdata.....	37
Figure 40: Request of navdata between the client and AR.Drone 2.0 [38].....	38
Figure 41: node-ar-drone-pilot file structure with dependencies on ar-drone and qrar libraries. Application files structure.....	39
Figure 42: node-ar-drone-pilot file structure with data obtained on the flight. In the folder log we have the nav data and magneto data, in the video folder, we found the video file recorded. Data files structure.....	40
Figure 43: node-ar-drone-pilot structure. Processed information flow between different parts of the application and AR.Drone 2.0.....	42
Figure 44: A visual representation of the project execution carried out in a garage of the University Jaime I of Castellón.....	43
Figure 45: The Wi-Fi connection between client-AR.Drone 2.0.....	43
Figure 46: Sequence diagram of the application node-ar-drone-pilot.....	44
Figure 47: drone-pilot.js execution	45
Figure 48: Sequence of instructions to initialize the system. Takeoff, compass calibration and change configuration to the bottom camera.....	45
Figure 49: Sequence of instructions to turn on the right 90° and continue straight.....	45
Figure 50: Sequence of instructions for landing	45
Figure 51: Sequence of navigation in tests carried out in the garage of the University Jaime I of Castellón [53].....	46

1. INTRODUCTION

1.1 Introduction

In the era of new technology advances at a frantic pace, the world of aviation has not been left behind. Airplanes have evolved into one of the means of transport and become safer. Besides airplanes, different aerial vehicles used have appeared, transport and leisure. Namely, aerial vehicles have gone from having only the function of transporting people or goods to being remote control toys used by children, creating a market that has expanded worldwide creating companies dedicated exclusively to it.

Since 1903, the Wright brothers managed to fly a few meters with a motor-propelled aircraft, the changes undergone by the world aviation have been very large. Improvements have been happening and have managed to create lighter and stronger aircraft, very different from the first wooden aircraft materials.

Early pilots who crossed the skies flying, used the first techniques and technologies for air navigation to be able to guide the plane to the destination, they used observation, speed, heading and time to estimate their position. To know the position in the airspace of the plane, attitude, pilots watched the horizon be sure they were flying in the right position relative to the ground. At that time, the pilots only had their view, a map, a compass and a watch for navigating.

In the 1920s, new equipment was introduced in the cockpit, to help pilots in their flights, bubble of liquid to keep wings level, a barometer to measure heights of flight, called altimeter, which told the pilot his altitude above ground. A compass to indicate to the pilot the actual course. The first navigation aids were the aerial beacon, acetylene lamps built.

In 1929, Lawrence Sperry introduced the artificial horizon that works on gyroscope principles. Artificial horizon shows the orientation of the aircraft relative to the horizon. With it is possible to know the angle of pitch and roll relative to the ground [1].

In 1961, Dr. Charles Stark Draper began to develop the Apollo Guidance Computer for controlling the navigation and guidance of the Apollo space program, which accomplished landing the first humans on the Moon. Dr. Draper invented and developed that technology that allows navigating by sensing changes in direction and speed, using gyroscopes and accelerometers. A key part of that technology was called Inertial Measuring Unit (IMU) [2]. Nowadays, the aircrafts are using Inertial Navigation System (INS) and Inertial Guidance System (IGS), to tell the pilot the precise position where they are flying.

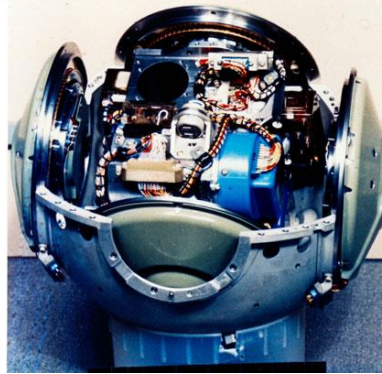


Figure 1: The Apollo spaceship (IMU) for navigation guidance and control to carry men to the Moon and back, that contains three gimbals, platform electronics, accelerometers and gyros [2].

Nowadays global positioning systems have changed our professional activity in many sectors, as well as our daily lives. GNSS (Global Navigation Satellite System) have reached such importance today, that the most important nations have or are in the process of having its own satellite constellations (see GPS, GLONASS, Galileo and Compass) to serve all.

While outdoor GNSS systems are the undisputed solution for positioning, urban, hilly, and wooded and most notably in areas inside buildings signal availability is very low, so the systems do not apply in these contexts. It has been established therefore looking for a system equivalent to GNSS positioning capabilities to operate within an indoor building. Today, neither the market research in universities offers an "Indoor GPS" to be imposed clearly. Shaping the inside of a building in terms of propagation of a signal is not at all easy, but it is not an obstacle to good approximations is published with increasing frequency.

Large technology companies are now interested in the indoor location. They are seeking to have a compact solution that can be integrated into their mobile devices, taking advantage of its computing power and new sensory capabilities of these devices. There are many applications for mapping and navigation based vision systems.

In the field of mobile robotics, the problem of indoor location and navigation solutions has long been sought. Industrial robots perform those activities almost exclusively inside buildings as well as warehouses, factories, hospitals, etc. These robots are increasingly better equipped in terms of sensory capacity, energy independence, and computing power. The ability to achieve the objectives and make decisions to overcome unforeseen situations is the next step forward for mobile robots on their way to autonomy.

In recent years, there have been a variety of unmanned aerial systems (UAS) that allow it to be controlled remotely or automatically. These devices can have many uses. That is why it is important to use those that may be efficient, fast and without putting the lives of pilots at risk for all kinds of tasks. Depending on the task to be

performed, the UAS can vary in structure; hardware and software they use, for instance the UAS can be differentiated basis with fixed or rotary wing structure. UAS have a set of sensors that allow them to capture information about the current flight and the environment. The use of UAS indoor for industrial applications is growing and many companies are interested in its use and develop.

The emergences of new technologies are contributing to new remote navigation and autonomous system. This project will discuss and use an autonomous indoor navigation system for UAS through inertial systems and landmarks. UAS has become fashionable in recent years because of its military use. Such is the population expansion that governments have had to enact laws to regulate their use. For example, in Spain, the Agencia Estatal de Seguridad Aérea (AESA) is responsible for controlling the use of remote-controlled aircraft.

There are small differences between the UASs used for research and development and those used for recreation, as some of these models for this purpose are usually "modified" to some extent, either in hardware and software level. In the market, we will find many of these models in specialized websites or on the websites of the same companies that make them. One of the highlights is the AR.Drone.

It is no coincidence that the most used is the AR.Drone, as it is one of the most popular and which also will be used in this project. Full description and main characteristics are detailed below, but we can say that is a civilian quadcopter for recreational use which is controlled by a mobile device or via a computer [3]. It is currently in version 2.0 (July 2012) and applications can be developed with a software development kit (SDK) that can be downloaded freely in a platform for this purpose [4].

The reasons why we have opted for the AR.Drone 2.0 model and not another UAS are several.

- First, his growing fame has made many people interested in it, so we can say that there is plenty of information and documentation on the network.
- Secondly, the fact that is supported by mobile devices and the operating system, which makes the SDK, is very functional and adaptable.
- Likewise, the fact that there is a development-oriented application for the AR.Drone platform is a point in its favour.
- We can also say that among the characteristics of the AR.Drone, we would highlight a couple of cameras through which we can see the flight. This makes it ideal for certain applications.
- On the platform SDK, there is much interaction between developers because it has a forum for questions and a more or less complete API.



Figure 2: Parrot AR.Drone 2.0 used for developing this project [38].

In short, the SDK is a strong point on which to rely as our choice argument. There are too many commercial drones that have a method of developing applications, as for more sophisticated we have to migrate to platforms such as Arduino microcontroller or concrete projects of some universities [5].

1.2 Motivation

The motivation for this project stem from an interest in a technology that becomes more popular, UAS (Unmanned Aircraft System), UAV (Unmanned Aerial Vehicle) or RPAS (Remotely Piloted Aircraft Systems) it is a flying platform that can fly with different kinds of sensors (cameras, IR cameras, Lidar, etc...) and without human pilot on-board. Today with the advances of new technologies, UAS have become an indispensable tool for certain purposes in any field of human activity. Either to inspect a dangerous ground or to facilitate the task of observing remote areas, its use is extensive. These systems can take a lot of information for different uses:

- Search and Rescue (SAR): Search and locate people and animals in natural disasters, accidents or any emergency
- Agriculture: Control of agricultural subsidies, detection of nutritional stress in crops, detection of water stress on crops for efficient water management, early detection of diseases and pests in crops, quality indexes of crops, Inventorying crop areas, fumigation, etc.
- Inspections: Inspections of wind turbines, power lines, train tracks, pipelines, roads, etc.
- Surveillance/Security: Coordinate security operations, sports events, floods, public events, traffic sensing, etc.
- Science and Research: Forest monitoring, wealth management, observe a volcanic eruption or document an archeological excavation, ocean and coast research.
- Aerial Photography and Video: Images to print and television news, photography and video at low altitude, spherical and panoramic photography, monitoring and recording of events, oblique photograph, etc.

- Surveying/GIS: Frequent updating of map databases and cadastral, topography, photogrammetry, remote sensing, etc.
- Transport Payloads: Transport small goods in nearby areas
- Environment: Endangered species, forest fires, contaminant spill, pollution, forest monitoring, watersheds, environmental impact and control areas, etc.



Figure 3: Global Hawk, NASA's unmanned aircraft system for high-altitude, long-duration Earth science missions [5].

Although an UAS has many advantages for certain tasks, and they are very safe in flight as they are controlled if an UAS fails to receive external control signals, having a large mass uncontrolled flying without control it can become very dangerous. This makes conducting research on an autonomous UAS very challenging. For terrestrial mobile robots or robotic manipulators, basic visual control servo series is a well-studied problem with a series of solutions provided, but robots are still many challenges to fly. The problem is greater because flying UAS operating in 3D-space as opposed to 2D surface ground robots navigate.

Indoor navigation for UAS is an interesting area for research because there are some people, institutions and companies researching in this field. There are different ways to create an indoor navigation system. In this project we develop an indoor navigation based on the Inertial Navigation System and landmarks, using Quick Response (QR) codes as landmarks.

The research behind the project could be interesting in the future for different applications like search and rescue (SAR), mapping, working in dangerous areas for people, surveillance, industry applications, and others.

1.3 Aims and Objectives

The aim of the project is to research in autonomous indoor navigation method through QR codes and with the use of UAS, in this case, an AR.Drone 2.0 of Parrot Company. The point is that the UAS could navigate and do different operations through the indoor navigation system.

1. Research into current autonomous navigation with INS and QR codes.
2. Research into algorithms for QR codes system.
3. Identify the best method for autonomous task based on indoor navigation through INS and QR codes.
4. Design a prototype for AR.Drone using different sensors and parts.
5. Develop and code the algorithms for indoor navigation through QR codes.
6. Acquire conclusions of the system solution and trying to improve.
7. Develop ideas to implement in the future.

The work presented in this project has been developed following different sources where we can use to gather important data. These sources of information come from many places, previous research, open source information and technical documentation from manufacturers.

For this research we will use the AR.Drone, It will be important to know and understand his navigation and control technology [3] [6] as well as the tracking algorithms to autonomously following dynamic targets at low altitude [7] to develop the base of this project. The AR.Drone 2.0 is a quadcopter built by the French company Parrot. The equipment on-board AR.Drone 2.0 It is composed by two cameras (front HD. 720 p 30 FPS, below QVGA de 60 FPS). Ultrasonic sensors to measure the altitude of progress, allowing for more stable flight and hovering. 1GHz processor and 32-bit ARM Cortex A8, and Wi-Fi b g n. 3-axis gyro with an accuracy of 2000°/sec, 3-axis accelerometer with an accuracy of +/-50mg, 3-axis magnetometer to within 6 °. One USB 2.0 and RAM 1GB DDR2 200 MHz among others.

We use QR codes and the INS like a new technique for autonomous navigation for UAS on indoor building in closed-loop, where we cannot use GPS system. This system is useful for outdoor, but in this research, we only test it in indoor.

For developing this project it is important to use a variety of documentation about AR.Drone software development kit (SDK) [8] and node JavaScript [9], which provides the SDK for develop software and the AR-module for launch the code to the UAS.

1.4 Challenges

The indoor navigation system must overcome numerous hardware and software design challenges including:

- **Positioning accuracy:** The position of the UAS will have a range of error due to the mistakes of the sensor noise, bias and scale factor errors that cause a significant increase in the position estimation errors [10]. The use of low-cost sensors increases these errors, in addition, to greater area overflow the error increases. In this case, small areas will fly to perform tasks in a closed loop. The use of QR codes helps us improve accuracy as it can include different information in them, such as their position.
- **Power and computational constraints:** Due to computational limitations and flight autonomy (battery) in AR.Drone [3], the system designed for this application must be developed within these limitations.
- **Application develops and security:** The system must know the needs of application development as well as system security of people and property with which to engage. The system must prepare a manual control system whereby if the system is compromised the user controls the system manually.
- **Scalability:** The system should be able to allow scalability, allowing adaptations to incorporate the system for improvement. Proximity sensors for improved safety, embedded systems, laser sensors, electromechanical systems, Laser Imaging Detection and Ranging (LIDAR), artificial vision software etc. to increase the accuracy, capacity and safety of navigation.

1.5 Regulations

In Spain, the Agencia Estatal de Seguridad Aérea (AESA) is responsible for controlling the use of remote-controlled aircraft. This entity has issued the flight of UASs is not allowed in public spaces with commercial or professional purposes, and that if a user wants to use them for any purpose other than recreation or sports, it is necessary to have to request authorization from AESA. As for indoor using these aircraft is not regulated, so may be used under the responsibility of the pilot [54][55][56][57].



Figure 4: National and international aviation safety agencies, Agencia Estatal de Seguridad Aérea (AESA, Spain), European Aviation Safety Agency (EASA, Europe), European Organization for the Safety of Air Navigation (Eurocontrol, Europe) and International Civil Aviation Organization (ICAO, worldwide), agencies that regulate the activities of UAS [54][55][56][57].

2. OVERVIEW

2.1 Indoor Navigation

In the past, we have seen the evolution of Global Navigation Satellite Systems (GNSS), GPS is an example of this evolution. Navigation in outdoor environments is a mature technology nowadays, but there are several problems like it is no possible to receive good quality satellite signals, somebody could be jamming the signals or inside most buildings it is no possible receive signals. Many technologies are solving these problems.

The indoor localization technologies can be classified into three categories [11]:

- Technologies based on signals of opportunity (SOP).
- Technologies based on pre-deployed infrastructure.
- Others technologies.

For a complete satisfactory navigation by mobile autonomous robots, it is required complete the next four steps:

- Perception, capacity to extract data from the environment by different sensors.
- Localization, process for determining the position in space.
- Cognition, make decisions to achieve goals.
- Motion control, the control system commands to manage actuators for moving in the right direction to the next position.

2.2 Indoor Localization Techniques

2.2.1 Technologies Based on Signals of Opportunity (SOP)

The signals of opportunity normally are electro-magnetic signals, such Wi-Fi, TV, radio, cell-phone etc. The main advantages are the low cost and wide coverage. These signals are designed for other purposes but we can use them for positioning [12] [13] [14] [15].

2.2.1.1 Wi-Fi and Bluetooth

Wi-Fi and Bluetooth are based on radio-based technologies and make use of received signal strength (RSS) for positioning. This technique measures the received signal strength, is based on the attenuation experienced by the signal as it moves away from

the source, calculating the attenuation suffered can calculate the distance to the emitter. This technique uses the attenuation of the received signal to locate the mobile device, and can estimate the distance between the mobile terminal of each access point, but the relative distance-power of the received signal is not very clear, having multipath, reflections, diffractions etc. One advantage of this technique is that no synchronization is required for the distance measurement, it is easy to implement and inexpensive. One of its major drawbacks is the variability of the signal which causes multipath and interference. The accuracy is between 1-3m [16][17].

There are two techniques used by the RSS. The first one is triangulation, which involves determining the position of an object based on triangulation which is the intersection of at least three circles centred on each known position (in this case, stations or access points) fixed, the radius must be related to the parameter measured (in this case, received power). The accuracy of triangulation depends on the precision of each of the measurements. The measurements may be distorted due to the orientation of the antennas, multipath, attenuation by the presence of obstacles. The second one is fingerprinting based on comparing the position data stored in databases previously with the user position in the real time; they can be used both unilateral and multilateral.

2.2.2 Technologies Based on Pre-deployed Infrastructure

Depending on the needs is possible to install certain infrastructures employed to carry a positioning system. Many technologies based on pre-deployed infrastructure based on ultrasounds, infrared, ultra-wide band, etc. is expensive and the coverage is limited but on the other hand, they have higher location accuracy [18] [19] [20] [21].

2.2.2.1 Radio Frequency Identification (RFID)

Radio frequency identification (RFID) it is a means of storing and transmitting data via electromagnetic waves supports an integrated circuit RF. An RFID system comprises mainly: RFID Readers, RFID (active or passive) tags, and communication between them. Readers read the information issued by the tags, both using an RF protocol defined.

Active tags are small transducers (transceivers) able to transmit their ID (or any other data) in response. The integrated antenna allows measurements in ranges of tens of meters. The accuracy of this system is around 2 meters. SpotON is a popular indoor 3-dimensional location technology based on RFID. Objects are located by nodes of homogeneous data acquisition without central control. The SpotON tags use the received strength signals (RSS) value to estimate the distance to other tags. Exploit the tags density and correlation of multiple measures to improve the accuracy and precision [22].

2.2.2.2 Ultrasound

Ultrasounds are not perceptible acoustic waves by humans, namely any frequency above 20 kHz, values between 1 and 20 MHz are used. The main applications of ultrasound versus conventional radio waves in the area of the location come from the fact that the speed of ultrasound is approximately the speed of sound ($v \approx 343 \text{ m/s}$), while radio waves travel at the speed of light ($c = 10^8 \text{ m/s}$), so the packet radio does not affect the measurement. This allows send a radius message and a pulse of ultrasound at the same instant from a transmitter and calculate the difference between the arrival time of radio packet and ultrasonic pulse on the receiver, thereby a relative distance is obtained. This technique is called Time Difference of Arrival (TDoA) techniques.

In ultrasound applications, the localization transmitter and receiver are separated, and must have Line of Sight (LOS). The use of ultrasound many everyday actions can generate significant noise in the frequency of ultrasound, although not perceptible to humans, such as opening a door or chafing between metals.

Dolphin project [23] proposes an algorithm such that the overall location in the system is obtained by calculating the positions distributed. It sends both an RF signal and an ultrasound (US) and TDoA is measured between them. The new algorithm is that simply having a small number of known nodes with fixed and calculated positions can know where the other nodes are, without being necessary to receive the signal from these reference nodes directly.

This distributed system has the advantage that it is easily scalable since it is not necessary to have a relatively large infrastructure or follow a certain pattern of deployment. The disadvantages are that the position error may be high because the current position so is not received, but only in cases that receive a signal from a transmitter node.

2.2.2.3 Infrared (IR)

The infrared localization system uses emitters and receivers sensors to determine the position. The disadvantage of this system is in the short range and also requires a line of sight (LoS). Infrared systems cannot works under natural light and calibration is typically needed when placed in a new environment. An example of an application in UAS is shown in [24]. A positioning system for UAS using the infrared transmitter in the UAS and three directional active sensors that receive the signals from the UAS. The accuracy is about 2 meters and the limitations are the range of the system and the need of LoS.

2.2.2.4 Ultra-wideband Radio (UWB)

UWB systems are based on shipping ultrashort <1 ns pulses with a very low duty cycle $1/1000$, this makes it possible to filter the original signal reflected, which provides greater accuracy. However, it is employing a wide width > 500 MHz.

One advantage compared to RFID systems is that they can emit multiple frequency bands simultaneously from 3.1 to 10 GHz. They are transmitted over much shorter periods, consume much less energy than the RFID and can operate at larger radio.

They can operate in close proximity to other RF signals without causing interference or suffer due to differences in frequency spectrum used. Given the short duration of the pulses, UWB signals are easy to filter to see which are right and which come from multipath. They can go through people, walls and other equipment with ease, except for metals and liquid materials, a problem that is solved with the strategic placement of readers.

The waveforms (Short-pulse waveform) allow determining a time of arrival (ToA) accurately and, therefore, the time of flight (ToF) of a burst of pulses from a transmitter to the corresponding receiver. The location by UWB operates the synchronization feature for UWB communication for very high precision indoor (20cm), so it is appropriate for 2D-3D real-time applications. The 3D location can be acquired by methods TDoA or Angle of Arrival (AOA). Both methods can be used together substantially reducing the density sensor for determining the position of a mobile robot [25] [26].

2.2.3 Others Technologies

In the others technologies, we can consider inertial navigation systems, computer vision systems, etc. These systems allow fully autonomous exploration without external signals [27] [28].

2.2.3.1 Inertial Navigation System (INS)

Inertial navigation systems (INS) are based on inertial measurement units called IMUs, to calculate a position using dead reckoning of an object, relative to its starting point, direction and speed.

With inertial navigation systems avoid relying on an infrastructure and a specific sensor like some of the tracking systems, INS use sensors such as accelerometers, gyroscopes and compasses to determine the distance and direction that is allowing these systems to position an object without any external infrastructure, which offers the possibility to use this system in any indoor environment [29].

Today still there are no applications using only INS for indoor positioning, are usually supplemented with other systems such as computer vision, the absence is due mainly to the measurement errors of these systems. The vibration magnitude is larger than the range of the accelerometer this makes the accelerometer saturate in time, called drift, the same is also noticed in the estimates of the orientation as a pitch and roll error.

Indoor positioning system should offer as accurately as possible when calculating the location of the object, considering that in the indoor location much more accurately than in outdoor spaces is required. The errors must not exceed one meter. Previously the AR.Drone contained a position estimate within the drone's navdata structure based on INS [3].

TABLE OF LOCALISATION TECHNIQUES		
SYSTEM	COVERAGE	ACCURACY
RFID	Several rooms	2m
Ultrasound	Single room	2cm
Radio-based	Several rooms	3m
Ultra-wideband	Several rooms	<1m

Table 1: Comparative summary positioning systems based on radio, ranked by technology, coverage, and accuracy.

2.3 Preliminary Theory

2.3.1 Inertial Sensors and Heading

The inertial sensors are proprioceptive, as measured internal positions and accelerations of UAS. The new electronic technologies can get these devices at very low prices, so intensively used for stability and support in navigation in all types of mobile devices, aircraft of all types and also in the world of robotics. By contrast, heading sensors (or course), mainly electronic compass is an exteroceptive sensor as it responds to external factors to the robot, see Earth's magnetic field. These sensors have undergone a similar revolution to the inertial sensors in terms of price and technology in recent years, making them widely used in many fields. Although some authors show inertial sensors encompassed within heading sensors, there are differences in operating principles but not in purpose.

2.3.1.1 Electronic Compass

This area is dominated by two technologies: electronic compass Hall effect and the type of Fluxgate. Both use the Earth's magnetic field to detect the angle of the UAS with respect to the magnetic north, but its operation is different.

Hall effect compasses are very popular in the world of robotics. Measuring the variation of the magnetic field, sensing the voltage on a conductor in the presence of a magnetic field. Basically it contains two semiconductor right angles, which can measure the magnetic field in two axes and determine one of the eight possible magnetic directions. Their prices are quite low but have some drawbacks, such as its slowness, poor resolution and its nonlinear behavior, which implies the need for additional circuitry.

Fluxgate compasses types have better accuracy and resolution, at the expense of larger size and price the Hall effect. It consists of two windings of a conductor around ferromagnetic cores placed one each at 90° . When current is circulated through the conductors, the magnetic field produces currents that are out of phase with each other. Measuring this gap can calculate the orientation of the magnetic field in two axes.

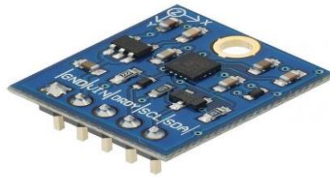


Figure 5: 3-Axis Digital Compass HMC5883L used in AR.Drone 2.0 [43]

Regardless of the technology used, the biggest drawback of the electronic compass is their sensitivity to the magnetic field created by other objects, which may impair the readings. The presence of metals in the buildings (structures, pipes, wires) has displaced the use of digital compasses on robots that operate indoors.

- Inertial sensors: An absolute inertial control includes the study of the six degrees of freedom of a vehicle in space (pitch, roll and yaw) and accelerations in three axes. Knowing the angle of rotation about the vertical axis and the longitudinal acceleration is sufficient to estimate the position. The accelerometers provide information about the displacement along the UAS time by the double integral of the acceleration recorded. This causes drift errors proportional to the square of the distance [30] [31].

2.3.1.2 Accelerometer

Accelerometers measure the external forces on the UAS, including the Earth's gravity itself, factor to be considered. Under the effect of an acceleration force it acts on the inertial mass, causing a displacement along a fixed structure. As accelerometer technology, the analogic output thereof is obtained based on the capacitive piezoelectric effect, or piezoresistive. Technology that best reflects the operation of such sensors is mechanical accelerometers.

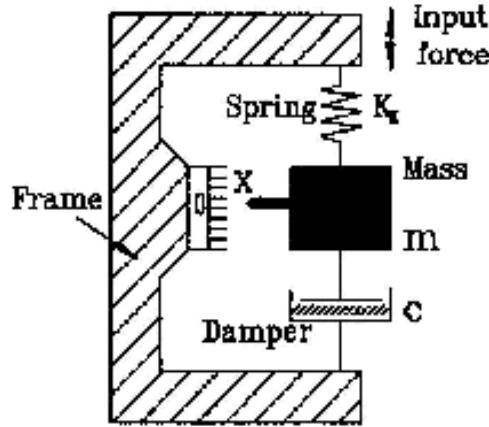


Figure 6: Basic components of a mechanical accelerometer [30].

If a force is applied to an accelerometer, we can look at the response of the second order mechanical system model by summing the forces acting on the proof mass.

$$F_{\text{application}} = F_{\text{inertial}} + F_{\text{damping}} + F_{\text{spring}} = m\ddot{x} + c\dot{x} + kx \quad [30]$$

As intrinsic characteristic, accelerometers have a very poor signal to noise ratio in small accelerations, and turns at low speed. They also suffer from large drifts, so that any deviation from any of the (vertical and/or horizontal) planes causes detect gravitational acceleration. The new accelerometers MEMS (Microelectromechanical Systems) are more valued than piezoelectric because they offer higher sensitivity and resolution. Moreover, MEMS accelerometers have no problems as piezoelectric with low frequency components, but produce weaker output levels, so they are more sensitive to external noise [30] [31] [32].

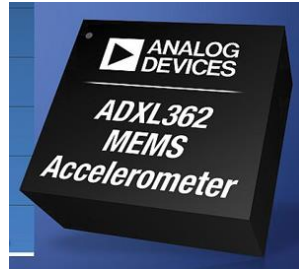


Figure 7: MEMS accelerometer. Given its small size, it is possible to integrate into many electronic devices [32]

2.3.1.3 Gyroscope

The gyroscopes measure relative rotation about an axis, from the properties of reference frames in rotation. The first technologies based on mechanical gyroscopes have given way to the MEMS technologies, but the physical principle remains the same.

The problem common to all types of gyroscopes is drift. Each of the measured movements contains an error, which accumulates over time. This, coupled with specific measurement errors of each technology, means not corrected, the sum of the errors could make measurements fall outside the requested tolerances.

Each gyroscope measures only the rotation about a single axis, then it is common to join three orthogonal axes so that they can measure 3D rotations. These groups of gyroscopes, accelerometers, and digital compasses are integrated, to build Inertial Measurement Units.

- **Mechanical gyroscopes:** Mechanical gyroscopes are the most primitive kind, more expensive and complex than those of new manufacturing technologies. They consist of a flywheel mass rotating at a certain speed about axis distributed on the periphery so that the moment of inertia of the rotation axis is still high.

The rotor is driven by an electric motor, being suspended by a pair of low friction bearings on each shaft end. These bearings are supported by a circular ring, known as internal gimbal ring, which, in turn, pivots in the second set of bearings which are rigidly to an external gimbal ring. There are three axes: the axis of rotation of the wheel, or rotor, an axis perpendicular to the wheel rotation, which defines the internal pivot and a third axis perpendicular to the previous two defining the outer pivot.

An important property of gyroscopes is that if the spinning wheel is applied a torque perpendicular to the axis, tending to overturn, the phenomenon shown in surprising principle, the wheel takes a slow rotational movement, but not

about the axis of the applied torque, but around the other perpendicular to it and the rotation axis of the wheel axle. This movement, which is known as precession motion, there is maintained while the gyroscopic inertia. This property can also be used for measuring the rotated angle.

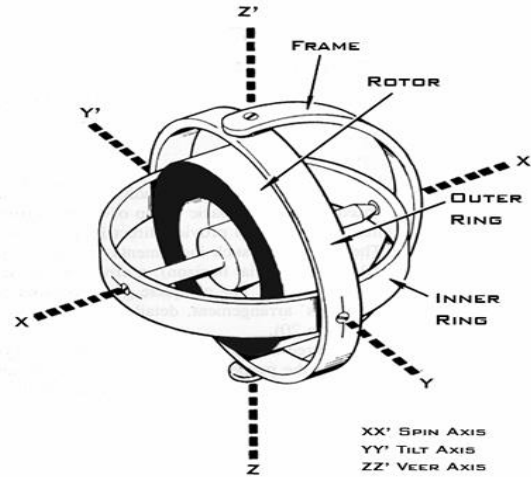


Figure 8: Basic diagram of the mechanical gyroscope. A mechanical device used to measure, maintain or change the orientation in space. [30].

Thus, if a vertical force is applied downward on the end of the rotor shaft (Fig.8), a torque occurs in the horizontal axis causing a precession rotating about the vertical axis. If both the instrument base rotates about the same vertical axis there will be a relationship between the precession and speed of rotation of the base. In fact, the faster the base turns, more force is needed to precession and speed of rotation of the base. This proportional relationship can be used to measure the rotation speed on the vertical axis. It should be noted that this variation provides gyroscope rotation angle of an axis perpendicular to the rotor axis.

- MEMS gyroscopes: Almost all gyroscopes MEMS (Micro-Electro-Mechanical Systems) They are based on the vibration of mechanical components in the direction of rotation. The operation rests on the principle of Coriolis acceleration, whereby an apparent acceleration appears within a system of reference that is moving. If an object moves in a straight line within a frame of reference, to an outside observer, the object's trajectory is curved.

MEMS Gyroscopes were employing vibrating quartz crystals to generate the required linear motion. Latest designs replace quartz crystals by oscillators based on silicon. Due to their small size and low price it is used in many devices [30] [31] [32].

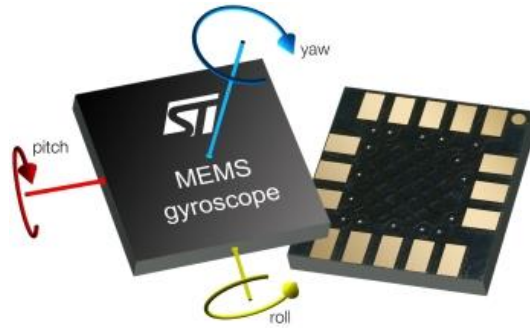


Figure 9: MEMS gyroscope from STMicroelectronics. Given its small size, it is possible to integrate into many electronic devices [32].

2.3.1.4 Inertial Measurement Unit (IMU)

An IMU (Inertial Measurement Unit) is a device that uses components as accelerometers and gyroscopes to estimate the relative position, velocity and acceleration of a moving vehicle. That term first used in the late forties gave rise to what is known as INS (Inertial Navigation System) which is a common component of navigation systems for aircraft and ships.

IMUs maintain the position estimate of the vehicle with 6 degrees of freedom: (x, y, z) and attitude (roll, pitch and yaw). The Chips usually estimate 6 degrees of freedom, also the position and speed. In Fig. 10 we show a block diagram of an IMU. The readings of the gyroscopes used to estimate the angle θ . In turn, three accelerometers placed orthogonally estimate instantaneous acceleration. Knowing the estimated angle θ , it is possible to know the position of the UAS with respect to gravitational acceleration vector and subtract the effect of it. Known initial velocity v_0 , the integral of acceleration is velocity v at that time, and integrating other time the position y is obtained.

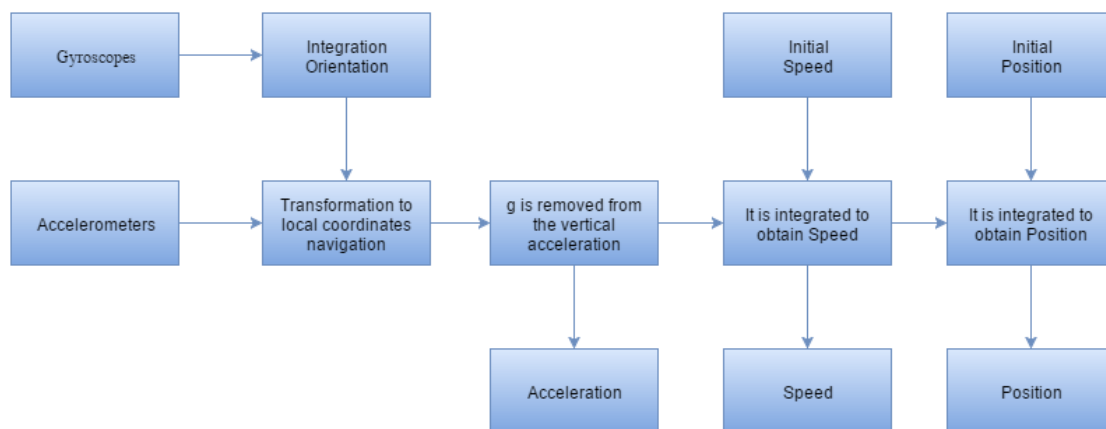


Figure 10: IMU blocks diagram. An electronic device that measures and reports speed, orientation and gravitational forces of a device, using a combination of accelerometers and gyroscopes [31].

The IMUs are extremely sensitive to measurement errors of the gyroscopes and accelerometers. Drifts in reading angular vectors cause of gravity are not deemed successful, and the effect of gravity vector appears quadratically when integrated a second time to get the position. Since a period of time long enough, the derivatives of the sensors cause unacceptable errors accumulate estimates, so an external source to provide a reliable position from which to start taking steps back is necessary. It is very common merge IMUs data with other technologies for reliable positions, such as GPS positioning technologies UAS operating outdoor or RF signals and vision systems indoors [30] [31].

2.3.2 Quick Response (QR) code

Quick Response (QR) code is a two-dimensional matrix created by the Japanese corporation Denso-Wave in 1994 [34]. QR codes were originally developed for logistics and tagging purposes but nowadays they are used for many other purposes. QR codes can be read faster than other technologies, they are robust as they are resistant to distortions, as perspective projection distortion and to damages and stains [33]. QR has large storage capacity, a single QR Code symbol can contain up to 7089 numeric characters, 4296 alphanumeric characters, 2953 bytes of binary data [34].



Figure 11: QR code - takeoff ().Takeoff instructions encoded in QR code with codigo-qr [51].

Some uses are from inventory and tracing and tracking, tourism and advertisement, among others [33] [35] [36]. There are many free applications to create and read QR codes [51].

The ability of a mobile robot to determine its location in space is a must to navigate completely autonomously task. Knowledge of actual position, as well as other objects and features of interest in the environment of the robot, are the basic foundations upon which operations are based navigation. The location allows it to be possible to plan paths to reach a specific destination while avoiding obstacles and it is essential for more complex tasks like building maps of unknown environments.

The system proposed is capable of autonomous indoor navigation and no communication with external entities is required. The system uses easily reproducible QR codes to obtain navigation instructions. The placement of QR codes on floors and

screens transmits the information to the vision system that is fused with inertial measurements in a timely and accurate manner on-board the UAS.

2.3.3 Introduction to Unmanned Air System (UAS) Quadcopter

The UAS use a reference system that determines the position and defines the possible movements it can make. This form allows it to perform calculations and other functions according to the current system position. The position of the system is referenced by a number of variables whose values vary the reference system used.

The number of variables used to represent a position also varies depending on the reference system. In the case of an air system it has three-dimensional space, we must consider the height where the system is, we need to use the coordinates in the x, y and z-axis. Regardless of the orientation of the system, the position thereof can be represented by (x, y, z), by varying the value of each variable with respect to the reference position (figure 12).

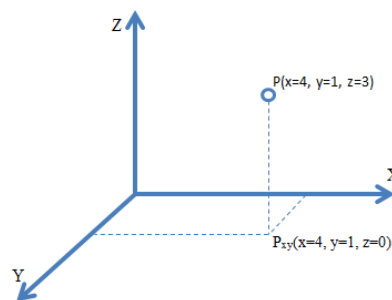


Figure 12: Three-dimensional reference system. A coordinate system is a set of values and points that allow uniquely define the position of any point in space [37].

An aircraft guidance system consists of three values each associated with one of the axes and who come to be as follows [37]:

- Pitch: It represents the frontal inclination to the axis.
- Roll: It represents the lateral inclination to the x-axis.
- Yaw: It represents the rotation around the vertical axis perpendicular to the plane, which in this case is the z-axis.

In figure 13 we can see a reference system of an aircraft, using the variables explained above, that is, the x, y, z and the orientation, pitch, roll and yaw. In this way, we can represent the current position and orientation of the vehicle.

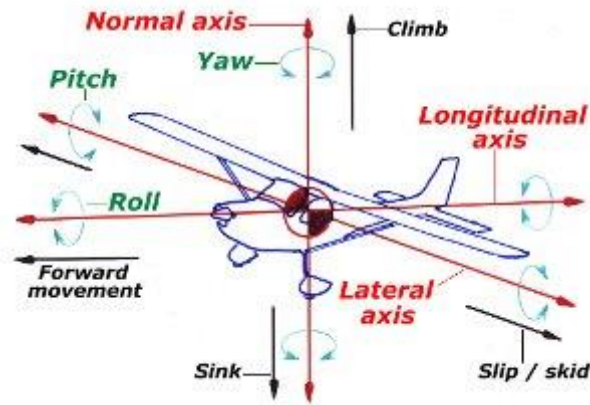


Figure 13: Pitch, roll and yaw axis definition for an airplane [37].

A quadcopter has four propellers that allow performing various movements, altering its inclination or other parameters. Each propeller is driven by a different motor, which adjusts the speed of each propeller varying the power of each one [38].

The power of each propeller is denoted by the symbol Ω , while for a power increase using the symbol Δ .

The structure used to provide a stable system is performed by placing the propellers in the form of a cross, and joining their supports to a common point, as shown in figure 14. Each pair of opposite propellers must rotate in the same direction. In addition, one pair must rotate counter-clockwise (which in this case is the pair front and rear in figure 14) while the other pair must rotate clockwise (which in this case is the pair left and right shown in figure 14).

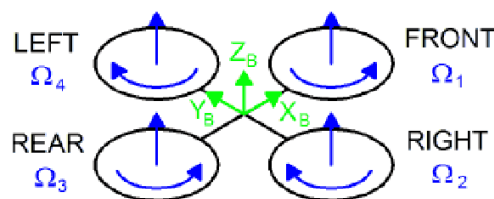


Figure 14: Cross structure of a quadcopter [38].

By altering the power supplied to each of the propellers you can achieve various movements quadcopter, using various combinations. Some basic movements with which you can move a quadcopter are:

- **Climb:** is increasing altitude quadcopter over a period of time, achieve a positive increase in the z-axis coordinate. This movement is achieved by providing an increase of equal power to all propellers, as can be seen in figure 15. Depending on this increase in power is achieved varying climbing speed.

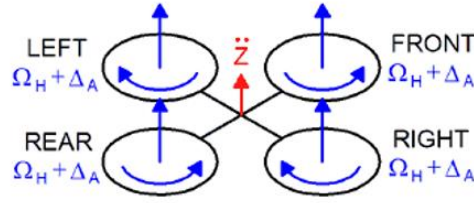


Figure 15: Four rotors with the same power for climbing [38].

Similarly, you can descend to the current providing a lower power to all propellers of the quadcopter.

- **Roll:** It is to perform a movement to move left or right for a period of time, that is, achieve an increase or decrease of the coordinate y-axis. This movement is achieved by supplying the same power to the propellers front and rear, and supplying, for the case of a rightward movement, less power than the pre-supplied to the right propeller. Furthermore, it must provide more power to supplied to the propellers front and rear to a propeller left (figure 16).

Thus, an inclination toward the right side occurs due to an imbalance of power in the y-axis. So, taking advantage of this inclination, the quadcopter is able to move right. Depending on the power of the propellers front and rear, the quadcopter moves with a given speed. Furthermore, depending on the potential difference between helices right and left, will be greater or lesser inclination.

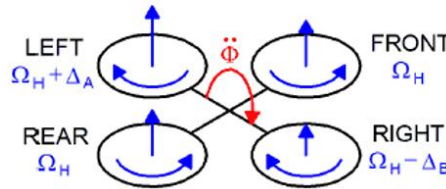


Figure 16: Roll movement [38].

Likewise, one can go left exchanging powers previously used on propellers right and left, more power to the propeller right than in left.

- **Pitch:** It is to make a motion to scroll forward or back during a period of time, namely, to achieve an increase or decrease of x-axis coordinate. This movement is achieved by supplying the same power propellers right and left, and supplying, in the case of a frontal movement, less than the previous propellers supplied to the power propeller front. On the other hand, it is due to supply more power to supplied to the propeller 2 and 4 to the propeller 3 (figure 17).

Thus, an inclination towards the front side of quadcopter due to an imbalance of power in the x-axis occurs. So, taking advantage of this inclination, the quadcopter is able to move forward.

Depending on the power of the propellers right and left, the quadcopter moves with a certain speed. In addition, depending on the power difference between propellers front and rear, will be greater or lesser inclination.

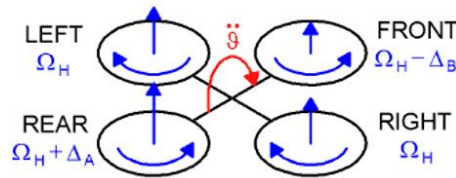


Figure 17: Pitch movement [38].

Likewise, one can go back exchanging powers previously used on propellers front and rear, that is, more power in propeller front than propeller rear.

- **Yaw:** It is to perform a rotational movement about the axis of a quadcopter with in order to change its orientation during a time period, namely, achieve an increase or decrease the yaw orientation. This movement is achieved by supplying the same power to propellers right and left, and providing, in the case of a left turn, a lower power to propellers provided above the propellers front and rear (figure 18). By creating a difference between the powers supplied to each pair of propellers, increases torque creating a turn in the opposite quadcopter to propellers they are rotating more power, which in this case is a turn with regard counter clockwise as more power propellers rotate clockwise. This rotation contrary to the direction of the propellers is because this rotation causes a pair reaction which tends to rotate the plane in the opposite direction about its axis, namely, is created an opposite rotation to the rotation of the propellers. Depending on the power of the propellers right and left, the quadcopter moves with a certain speed.

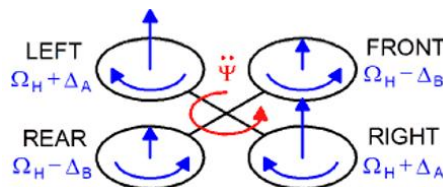


Figure 18: Yaw movement [38].

Similarly, it can turn right to exchange the powers used between the pairs of propellers, namely, providing more power to the pair front-rear that to the right-left.

Figure 19 illustrates the different movements depending on the power of quadcopter each rotor structure for a cross. Rotors in red are increasing power, rotors in green are decreasing power and rotors in white rotors are using the same power, without variation.

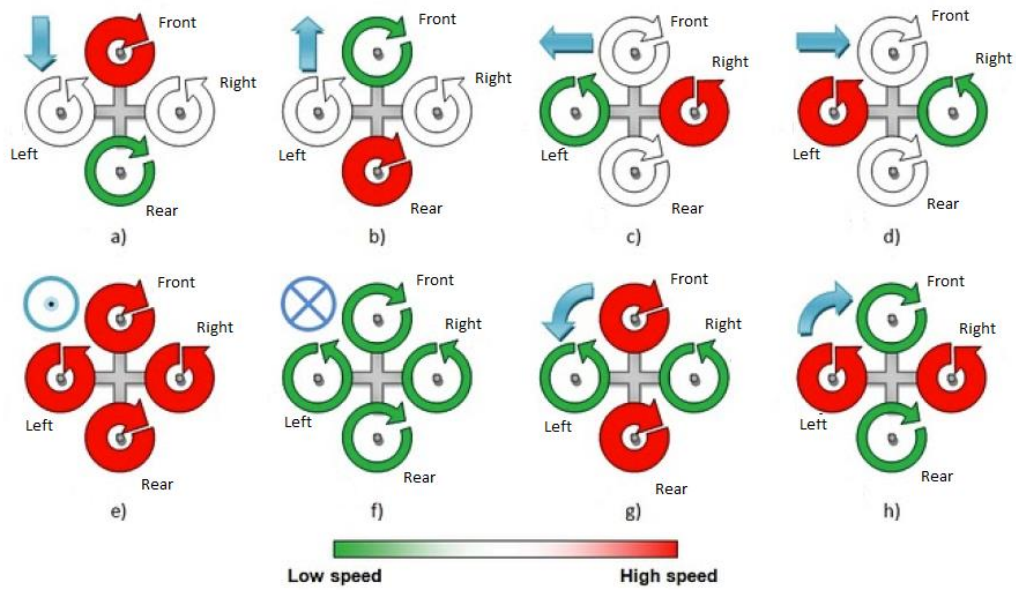


Figure 19: Behavior of the quadcopter rotors for different movements, a) backward, b) forward, c) left roll, d) right roll, e) up, f) down, g) left yaw, h) right yaw [38].

3. AR.DRONE 2.0

The AR.Drone is a quadcopter unmanned radio-controlled. By four electric motors and a microprocessor is able to fly and with a series of sensors can capture what is around and communicate with other devices. The AR.Drone also has two different covers for each type of flying: indoor or outdoor.



Figure 20: AR.Drone 2.0 (top and bottom view with indoor cover) [3]



Figure 21: Pitch and roll movements [3].



Figure 22: Rotation movement about its vertical axis [3].



Figure 23: Elevation and descending movements [3].

Among this series of sensors are two cameras and a Wi-Fi connector. The different motion sensors are located in the central hull. With Wi-Fi connector, you can control the AR.Drone from other devices such as PCs, mobile devices etc. To connect the drone this creates a Wi-Fi network called `ardrone_xxx`, so the user only has to connect to this network. To the user device's DHCP server AR.Drone will grant an IP address, which will be the IP address of the drone itself plus a number from 1 to 4. By sending AT command control and configuration is performed drone.

These commands are transferred via UDP port 5556 with a common transmission latency of 30 commands per second. Drone information (position, speed, altitude etc.), called navdata, are sent by the customer for the plane UDP port 5554. They are transferred at two frequencies: 15 times per second in Demo mode and 200 times per second in Debug mode, which would be when Augmented Reality games are created. The video sequence is sent by the client device AR.Drone port 5555 and pictures can be decoded using the codec included in the SDK. For the transmission of critical data, the drone uses a communication channel called control port. This alternative channel is used to retrieve configuration data and to recognize important information. These data go to port TCP 5559 Control.

The ultrasonic sensor is implemented in the lower AR.Drone determines the altitude at which the drone is located at all times. This sensor emits constantly towards the soil surface and depending on the latency with which the signals received as echoes draw up estimates of the altitude at which it is Regarding based sensors vision, are used two cameras to perform image capture in real time.

Cameras are:

- Frontal camera: With an image size of 640 x 360 pixels in size in widescreen format, this camera is capable of taking pictures in high definition (HD 720). It is the main camera AR.Drone to capture images of the environment. It is situated on the front of UAS and communicates with the on-board processor using the communications cable. It is the only camera capable of acquiring the full visual field of UAS.

- Vertical camera: It is situated at the bottom of the UAS and is typically used to achieve stability when the UAS is in the air without any type of maneuver. The quality of the images is less than the front, but, as in the front camera, the color is RGB.

The body of the UAS contains one of the most important parts of the device: lithium battery that can be recharged and allowing flight range of about 15 minutes. On the other hand, the shield frame protects the drone of the impacts that may occur during the flight [39] [40].

3.1 Hardware AR.Drone 2.0

3.1.1 Electronic Features

As for the electronic characteristics, the technologies used in the AR.Drone allows the user to control extreme precision and automatic stabilization features. Among AR.Drone technologies include the following [43]:

- Processor de 32 bits ARM Cortex A8 @1Ghz
- Linux 2.6.32 - Memory RAM DDR2 de 1Gbit @200MHz
- Wi-Fi b,g,n
- Connector USB 2.0
- 3-axis accelerometer accurately +/-50mg
- 3-axis gyroscope accuracy 2000°/ second
- 3-axis magnetometer accuracy 6°
- Pressure sensor with accuracy +/- 10 Pa
- Ultrasonic sensor for measuring the height above ground

3.1.2 HD Video Recording

- HD camera. 720p 30fps
- Wide angle lens: 92° diagonal
- H264 encoding base profile
- Low latency streaming
- Video storage on the fly with the remote device
- JPEG photo

- Video storage on the fly with Wi-Fi directly on a remote device or on a USB key

3.1.3 Structure

- Carbon fiber tubes: Total weight 380g with outdoor hull, 420g with indoor hull
- High grade 30% fiber charged nylon plastic parts
- Foam to isolate the inertial center from the engines vibration
- EPP hull injected by a sintered metal mold
- Liquid Repellent Nano-Coating on ultrasound sensors

3.1.4 Motor

- 4 brushless in-runner motors. 14.5W 28,500 RMP
- Micro ball bearing
- Low noise Nyla Tron gears for 1/8.75 propeller reducer
- Tempered steel propeller shaft
- Self-lubricating bronze bearing
- Specific high propelled drag for great maneuverability
- 8 MIPS AVR CPU per motor controller
- 3 elements 1000 mA/H LiPo rechargeable battery (Autonomy: 12 minutes)
- Emergency stop controlled by software
- Fully reprogrammable motor controller
- Water resistant motor electronic controller

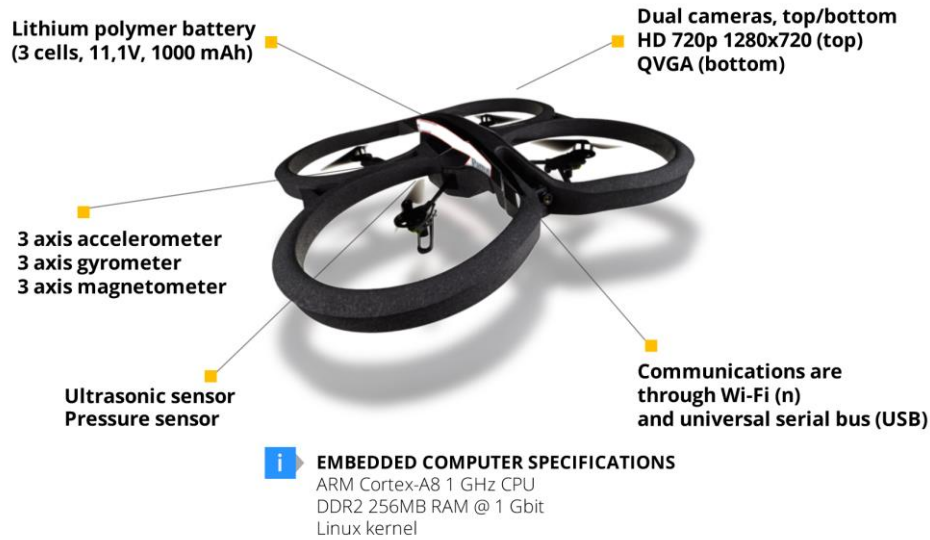


Figure 24: Electronic specifications and position in the structure of the AR.Drone 2.0 [43].

3.2 Software AR.Drone 2.0

3.2.1 Architecture

In figure 25 it can be seen that the AR.Drone has a multilayer architecture of four levels [41]: application level, thread level, host software and host hardware. In the AR.Drone 1.0 it was accessible to a level that the AR.Drone 2.0 cannot now, as this is due to an increasingly closed system performed. Currently, only the levels of implementation and the level of threads (partially) can be modified to a greater or lesser extent. It notes that any personal project that can be done with the SDK requires the management of threads to launch any application. This management is managed by the layer of management levels and communicates with the engine control AR.Drone, necessary to compile the project libraries and, in turn, communicates with the upper layer application level.

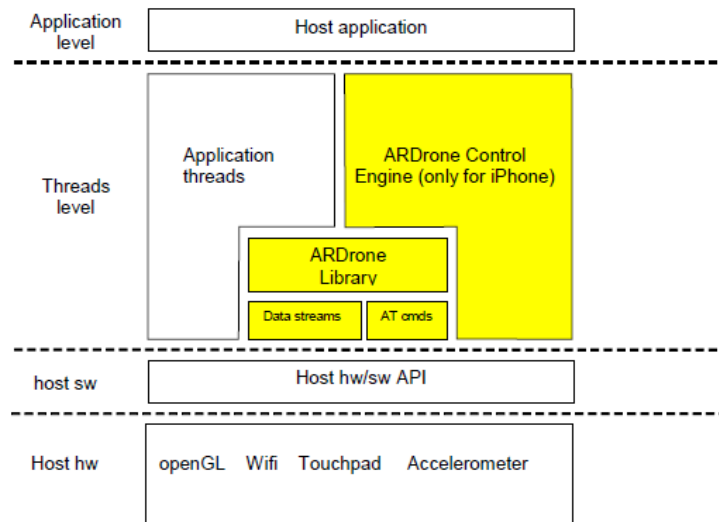


Figure 25: Here is an overview of the layered architecture of a host application built upon the AR.Drone 2.0 SDK [41].

3.2.2 SDK 2.0.1

The Software Development Kit (SDK) AR.Drone allows developers to develop applications and provides application programming interfaces (APIs) needed to compile programs. Depending on the version, has support for building applications on iOS, Linux, Windows, and Android. It is free and can be downloaded on the projects aimed at AR.Drone [4], in the same way that the Open Source software can be found on page Parrot [42]. Currently at the time of this writing, the SDK is at version 2.0.1

The SDK includes the following folders (focus only on important):

- ARDroneLib: It contains the API to set the AR.Drone.
- Control Engine: It contains specific files for iOS.
- Examples: It contains compiled examples made with ARDroneLib.

The most important part is the ARDroneLib folder, which is structured as follows:

- ARDroneLib.xcodeproj: Xcode project to develop applications in the integrated development environment Apple iOS.
- FFmpeg: Open source library that can record, convert and process audio and video. Multi-platform. In this case, it is responsible for processing the video ARDrone.

- ITTIAM: Prebuilt library (ARMv7 + Neon) and highly optimized video decoding for iOS and Android applications.
- Soft: It contains the specific code drone.
- VLIB: Video processing library AR.Drone 1.0. It contains functions to receive and decode the video stream.
- VP_SDK: General purpose libraries.

Important folders, in this case, are Soft and VP_SDK because the first is the skeleton needed to develop any application for the AR.Drone and the second contains useful libraries to manage certain aspects of the application programming.

Reflecting further on Soft / Lib / ar drone tool, we find the central part of the structure of the AR.Drone. Each folder includes a part of the management of the drone and when creating a new application structure will be similar to our program.

Main files and folders are:

- ardrone_tool.c: Initializes communication with the drone. It includes the main ().
- UI: It contains the code to handle the drone via a gamepad.
- AT: It contains functions to control the drone via AT Commands.
- Navdata: Receives and decodes the Navdata, which indicate the status of the drone.
- Control: Configure and manage the drone.

4. INDOOR NAVIGATION SYSTEM IMPLEMENTATION

4.1 Onboard Hardware

4.1.1 Raspberry Pi Zero

In this application, we used a laptop and a raspberry pi zero for the test. The raspberry pi zero is ideal because its form factor is reduced and can be installed inside the hull of AR.Drone 2.0. We can feed the Raspberry Pi by the USB connector inside the hull of AR.Drone 2.0. The communications among Raspberry Pi and Ar.Drone are by Wi-Fi [52].



Figure 26: Raspberry Pi Zero. Its size is ideal for this project because it can be installed inside the hull of the AR.Drone 2.0 [52].

- A Broadcom BCM2835 application processor, 1GHz ARM11 core.
- 512MB of LPDDR2 SDRAM.
- A micro-SD card slot.
- A mini-HDMI socket for 1080p60 video output.
- Micro-USB sockets for data and power.
- 40-pin GPIO header.
- Form factor, at 65mm x 30mm x 5mm.

The software installed on the Raspberry Pi Zero is the same installed on the laptop but adapted to the 32-bit architecture of Raspberry. We use Ubuntu, node, npm, FFmpeg cairo, etc. in the version for Raspberry Pi and the operative system installed, in this case, Ubuntu.

```
ubuntu@ubuntu:~/node-ar-drone-pilot$ uname -a
Linux ubuntu 3.18.0-25-rpi2 #26-Ubuntu SMP PREEMPT Sun Jul 5 06:46:34 UTC 2015 a
rmv7l armv7l armv7l GNU/Linux
ubuntu@ubuntu:~/node-ar-drone-pilot$ node -v
v5.5.0
ubuntu@ubuntu:~/node-ar-drone-pilot$ npm -v
3.3.12
```

Figure 27: Software versions in Raspberry Pi.

4.2 Software Prerequisites

4.2.1 Linux

To make our application, we use the Ubuntu operating system version 14.04.03, since it is the most stable version and compatible with other software used at this time [44].



Figure 28: Ubuntu version installed on the laptop.

4.2.2 Node.js

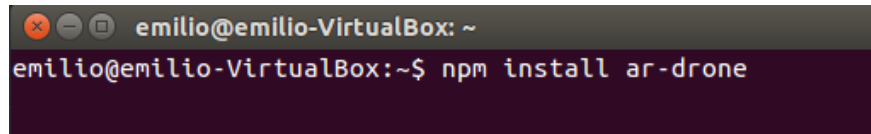
Based on a programming language JavaScript Node.js [45] is a programming environment. Work server side changes the notion of how this should work. Its goal is to enable creating highly scalable applications and writing code to handle tens of thousands of concurrent connections on a single physical machine. Thanks to its manager npm packages you can install and manage Node modules that are to be used. These modules are created by users Node.js developer community and allow you to extend the functionality of an object using a prototype. There are hundreds of modules, which work as packages or libraries, which can serve as templates, APIs, databases etc.

```
emilio@emilio-VirtualBox:~$ node -v
v5.1.1
```

Figure 29: Node.js version installed

4.2.3 Node ar-drone

Node ar-drone [46] is a node.js client for controlling Parrot AR.Drone 2.0 quadcopter. This module exposes a client API is a high-level support all features of drone while trying to make them easier to use. To use the Node ar-drone simply install by running the following command:

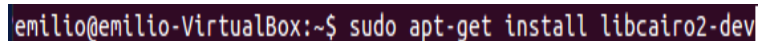
A terminal window with a dark background. The prompt is 'emilio@emilio-VirtualBox: ~'. The command 'npm install ar-drone' is entered and executed.

```
emilio@emilio-VirtualBox: ~  
emilio@emilio-VirtualBox:~$ npm install ar-drone
```

Figure 30: Installing ar-drone.

4.2.4 Cairo

Cairo is a 2D graphics library, used to provide a vector graphics-based with support for multiple output devices. Cairo is free software [47].

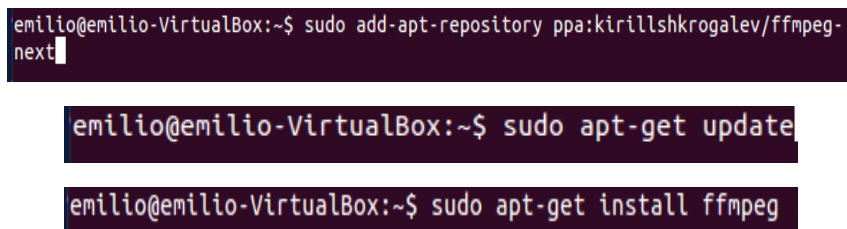
A terminal window with a dark background. The prompt is 'emilio@emilio-VirtualBox:~\$'. The command 'sudo apt-get install libcairo2-dev' is entered and executed.

```
emilio@emilio-VirtualBox:~$ sudo apt-get install libcairo2-dev
```

Figure 31: Installing Cairo library.

4.2.5 FFmpeg

FFmpeg is a free software Project able to decode, encode, stream and play multimedia data. It is developed under Linux, but it can be compiled by different operating systems [48].

Three terminal window screenshots showing the steps to install FFmpeg. The first shows adding a PPA repository, the second shows updating the package list, and the third shows installing FFmpeg.

```
emilio@emilio-VirtualBox:~$ sudo add-apt-repository ppa:kirillshkrogalev/ffmpeg-  
next  
emilio@emilio-VirtualBox:~$ sudo apt-get update  
emilio@emilio-VirtualBox:~$ sudo apt-get install ffmpeg
```

Figure 32: Installing FFmpeg.

4.2.6 Qrqr

Qrqr is a package to decode any QR code spotted by the cameras of AR.Drone. The QR code module used requires Cairo and FFmpeg libraries [49].

4.3 Drone-browser

This application allows us to control the use of the AR.Drone remotely through our browser. For the use of this application, we need to connect with the AR.Drone Wi-Fi and run the node server.js on the console then open up localhost:3001 and it is ready to work [50].

```
emilio@emilio-VirtualBox: ~  
emilio@emilio-VirtualBox:~$ node server.js
```

Figure 33: Manual control application execution for controlling AR.Drone 2.0.

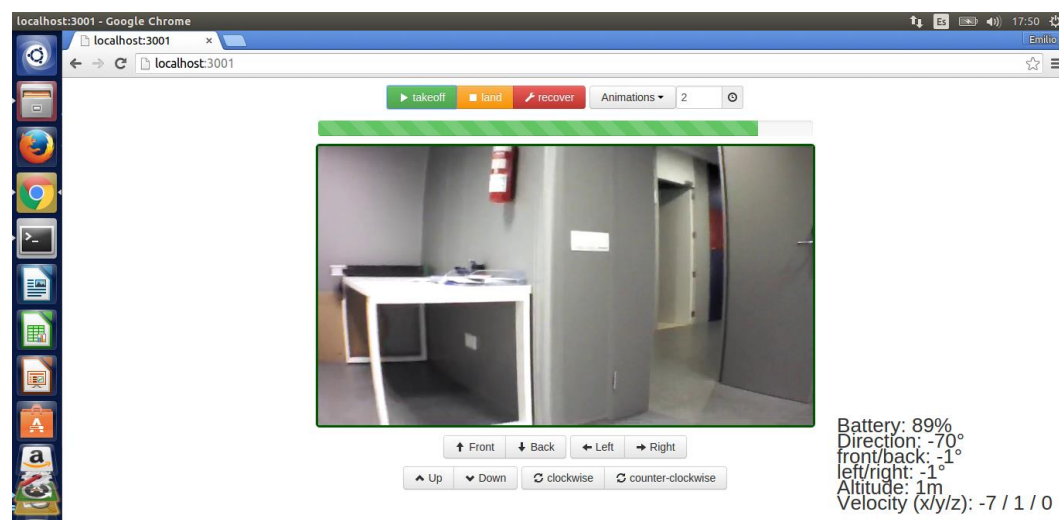


Figure 34: Manual control for AR.Drone 2.0. In the case of problems with the autonomous flight application, we will take the control of the AR.Drone 2.0 by this application.

4.4 Codigo-QR.es

On this website, we can generate QR codes completely free. Since this generator, we can easily create all QR Codes that we need filling out a simple form [51].

The image shows the 'Codigo QR para texto' form on the Codigo-QR.es website. At the top, there are tabs for 'Texto', 'Enviar SMS', 'Teléfono', 'Sitio Web', and 'Vcard'. The 'Texto' tab is selected. The form has a 'Texto:' label and a text input field containing 'takeoff()'. To the right of the input field, it says 'Caracteres: 9'. Below the input field is a 'Tamaño:' label with a dropdown menu showing '4'. There is a checkbox labeled 'Guardar codigo?' which is currently unchecked. At the bottom of the form is a 'Generar' button.

Figure 35: Dialog box of Codigo-QR. Application to generate QR codes with the information that we insert it [51].



Figure 36: Result of the instruction takeoff () in a QR code using Codigo-qr [51].

4.5 Main Application

The main application is node-ar-drone-pilot and its aim of is to make the AR.Drone 2.0 flying in a completely autonomous indoor navigation using inertial systems and QR codes. For environmental data, the AR.Drone offers a series of sensors to capture data about various magnitudes. Sensors that have incorporated the drone for this purpose are:

- 3-axis Gyroscope: through this sensor the AR.Drone can know at all time its orientation. It has an accuracy of 2000 °.
- 3-axis accelerometer: This sensor can measure the AR.Drone acceleration that moves and can get the speed on each axis.
- 3-axis magnetometer: the AR.Drone uses this sensor to know its accurate orientation with respect to the north.
- Atmospheric pressure sensor: through this sensor the AR.Drone can measure height that is and offer greater stability.
- Ultrasonic Sensors: by these two sensors located at the bottom drone, it measures its distance from the ground. They have a range of 6 meters.
- Front camera HD: record video or send it via Wi-Fi.
- Bottom camera QVGA: measures the speed that has the drone analyzing drone movement relative to the ground.

The structure of our application is shown in figure 37.

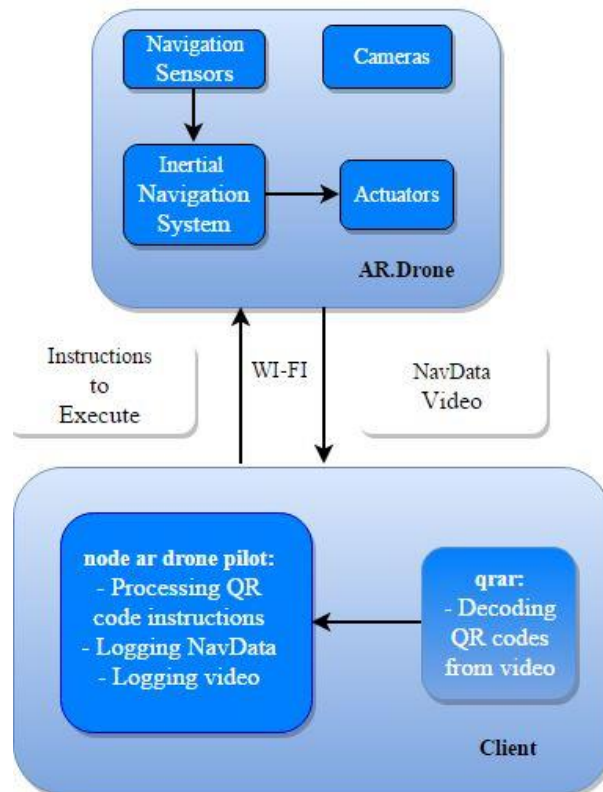


Figure 37: Diagram of the architecture of the autonomous navigation system.

4.5.1 Streaming Video

As mentioned above, the AR.Drone has two cameras, one camera HD 720p at 30 fps and is in the front of the AR.Drone and also another QVGA camera 480p at 60 fps which is in the lower AR.Drone 2.0 (Fig 38).



Figure 38: Front and bottom cameras in AR.Drone 2.0, cameras used to read QR codes and observe the environment.

The AR.Drone automatically takes care of encoding and sends the images from the cameras to the clients of the network. This video stream is sent by the UAS port 5555 and set out in that client port. The AR.Drone can only transmit video from a camera at a time, one of them being selected through parameter configuration video_channel.

The codec used to encode the video stream is the P264, a codec which is based on the H.264 baseline, only realizing we some modifications to optimize the speed with which encode and send the data [40].

4.5.2 Navigation data

For information on the current status of AR.Drone, it sends regular clients a structure with a series of navigation data (angles, altitude, speed). This structure is known as Navdata [39]. This structure is regularly sent packages through UDP port 5554 AR.Drone every 5 ms maximum, so this information is received about 200 times per second. In addition, packets are also sent to UDP port 5554 clients.

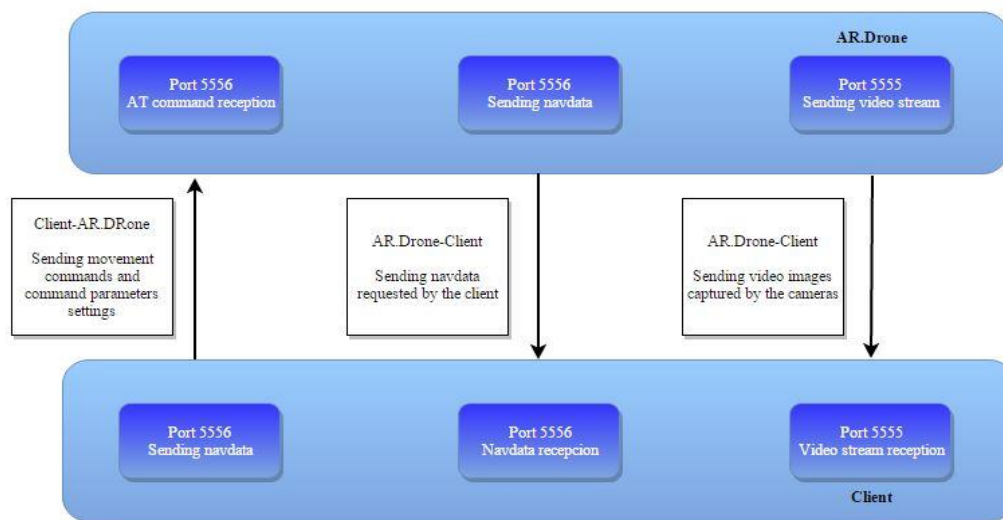


Figure 39: Communication Client-AR.Drone 2.0. Ports for exchanging information between client-AR.Drone 2.0, in this case, video stream, and navdata.

The client must follow a procedure for requesting the AR.Drone send to him the navigation data periodically (figure 40). The process is the following:

- The client sends a byte to the port Navdata AR.Drone.
- The AR.Drone responds with the current status.
- The client sets the parameter indicating AR.Drone navdata demo if you want
- Only navdata_demo (basic information AR.Drone) or all the information available from the AR.Drone.
- The AR.Drone sends the client requested navigation data periodically.

4.5.3 Node-ar-drone-pilot

The node-ar-drone-pilot application is composed of many different files like we can see in the figures 41 and 42 and we explain in the next steps:

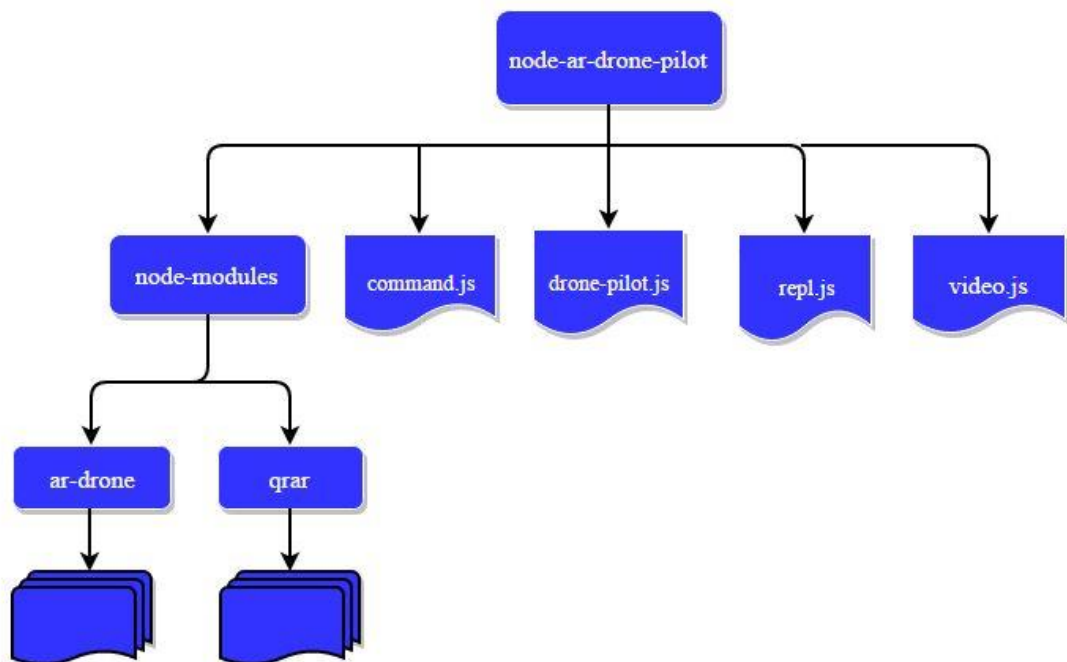


Figure 41: node-ar-drone-pilot file structure with dependencies on ar-drone and qrar libraries.

Application files structure.

- Node_modules: It contains qrar, the program to decode any QR code and the ar-drone to control Parrot AR Drone 2.0 quadcopter.
- Video.js: This program parses the streaming video from H.264 and creates the video file in mp4 format.
- Command.js: This is the program where are the functions to navigate, each QR code has their instructions in commands.js.
- Drone-pilot: This is the main program, read from the command line, It generates the files where the navigation data are stored, controls the video cameras and processes the QR codes. It is who generates the instruction to execute.
- Repl.js: The Read-Eval-Print-Loop (REPL) provides a way to interactively run JavaScript and see the results. It can be used for debugging, testing, or just trying things out. It is responsible for sending the instructions to AR.Drone that drone-pilot.js generates.

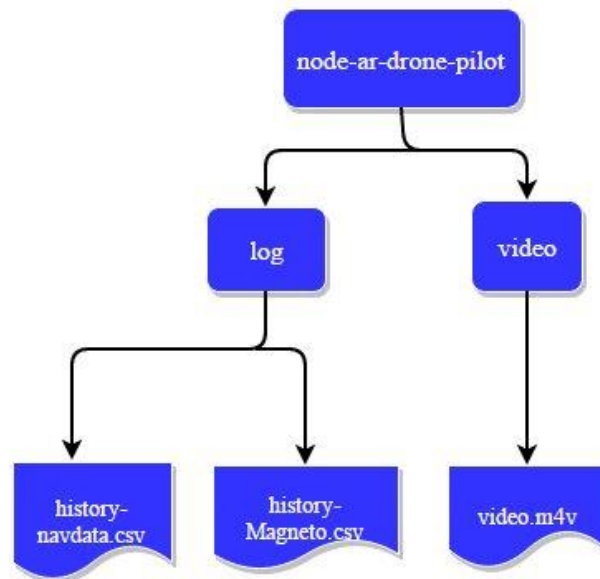


Figure 42: node-ar-drone-pilot file structure with data obtained on the flight. In the folder log we have the navdata and magneto data, in the video folder, we found the video file recorded. Data files structure.

- Log: We store all navdata files that AR.Drone send us inside log file. The files are in CSV extension.
- Video: In this case the video images received are stored as mp4 file.

4.5.4 Drone-pilot.js

The drone-pilot is the main program of the application. As shown in figure 43 all data flows passing through the drone-pilot.js. The information between client and Ar.Drone 2.0 is transmitted by WI-FI. In the next pieces of code of drone-pilot.js, we explain some of the main features.

Code to generate the video file where sequences of flight are recorded.

```
// Start recording
videoRecord.record(client, {
  videoFolder: videoFolder,
  name: `video-${flightName}.m4v`
});
```

The following code sequence generated files to store data generated by inertial navigation systems throughout the flight.

```
// Navigation data are stored in files
client.on('navdata', function(data) {
  var time = Date.now();
  var navdatatxt = JSON.stringify(data);
  var csvRowHistory = `${time},${navdatatxt}\n`;
  navdataHistoryStream.write(csvRowHistory);
});
```

```

// Check if magneto data is available
if( data.magneto ) {
    var csvRowMagneto =
`${time},${data.magneto.mx},${data.magneto.my},${data.magneto.mz},${data.magneto.raw.x},${data.magneto.raw.y},${data.magneto.raw.z}\n`;
    navdataMagnetoStream.write(csvRowMagneto);
}
});

```

With this code video images are scanned for searching QR codes that are in the video stream.

```

// Code scanning QR codes
var codes = new QRAR(client);
var lastExecutedCode = "";
var isFirstQRDetected = true;
var isReady = true;
function iterateArrayPausable(array, cb) {
    let i = 0;
    function loop () {
        let value = array[i];
        let wait = _.startsWith(value, 'wait') ? parseInt(value.replace('wait(', '').replace(')', '')) : 0;
        let operation = _.startsWith(value, 'wait') ? ()=>{} : console.log;
        setTimeout(function () {
            operation.call(null, value);
            i++;
            if (i < array.length) {
                loop();
            } else {
                if (cb)
                    _.defer(cb.bind(null));
            }
        }, wait);
    }
    loop();
}

```

In this part of the code the QR code is processed. The first QR code is read and its content is analyzed for checking errors, then the instructions assigned to that code are reading.

```

// When a QR detected is processed
codes.on('qrcode', function (code) {
    if( isReady ) {
        //console.log("Code:", code);
        isReady = false;
        // Check if it is a configurable code
        if( ! commands.isDefaultCode(code) ) {
            // This is a configurable code and is 1 char repeated N times
            // It separates the code char by char, groups by equals char, sorts them and take the char with
            // most occurrences
            code = _.chain(code)
                .words(/./g)
                .groupBy()
                .sortBy((el) => el.length * -1) // Descending
                .first().first()
                .value();
        }
        // Check if the code is different from the previous one. Executing the same code twice is not
        // allowed
    }
});

```

```

if( lastExecutedCode === code ) {
    isReady = true;
    return;
}

if( ! commands.isValidCode(code) ) {
    isReady = true;
    return;
}

```

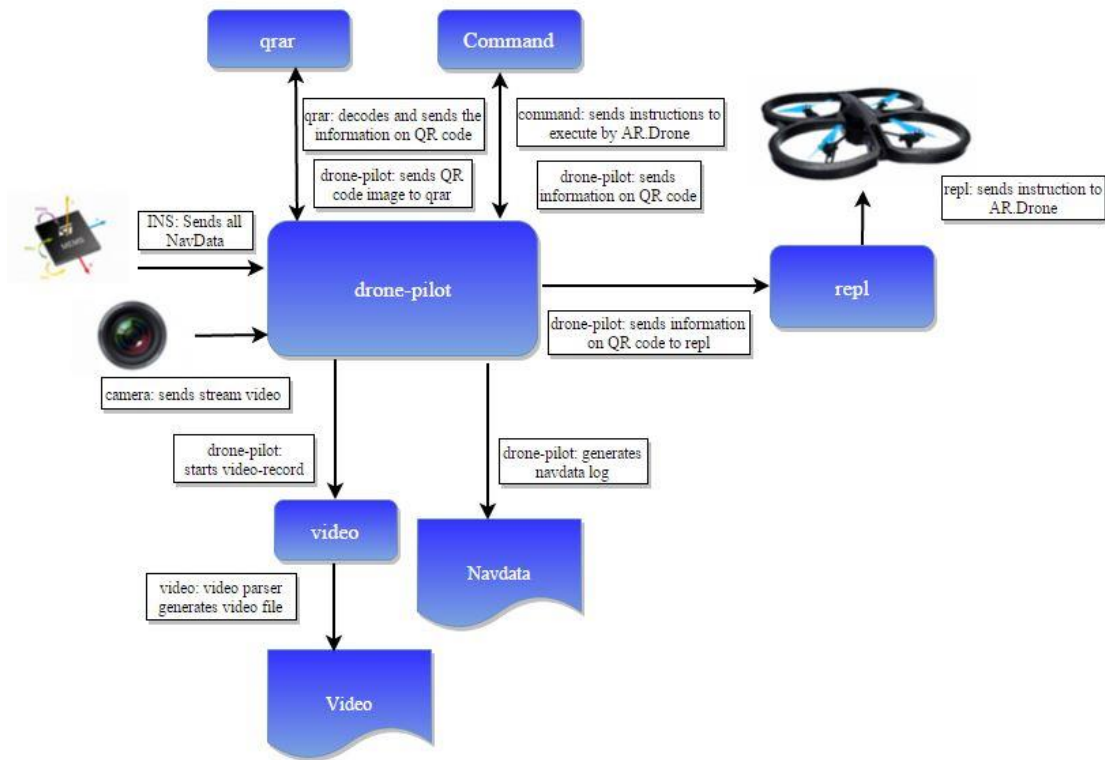


Figure 43: node-ar-drone-pilot structure. Processed information flow between different parts of the application and AR.Drone 2.0.

After running the drone-pilot application, the AR.Drone take off, do the calibration of the electronic compass, change front camera to bottom camera and move forward to find the next QR code. Once interpreted the QR code, the AR.Drone executes instructions to find the following QR code. Until the last instruction, landing.

The sequence of instructions used in this application is as follows:

1. QR code: b {takeoff(), stop(), calibrate(0), config("video:video_channel", 3), front(0.035)}
2. QR code: c {stop() , clockwise(0.5), stop(), front(0.035)}
3. QR code: a { stop() , clockwise(0.5), stop(), front(0.035)}
4. QR code: d { stop() , clockwise(0.5), stop(), front(0.035)}
5. QR code: e {stop(), land() }

5. TESTING AND RESULTS

The objective of this experiment is to see if the system created for autonomous indoor navigation by inertial systems and QR codes is feasible and see the results. The test was carried out in a garage of the University Jaime I of Castellón. The outline of the overflowed area is about 50 square meters, with a height of 3 meters. The area is well lit. QR codes have an A4 size, each vertex of this area consists of six QR codes spaced apart about 30 centimeters and the distance between the four corners is about 7 meters. Within the area, there are two columns that we should avoid.

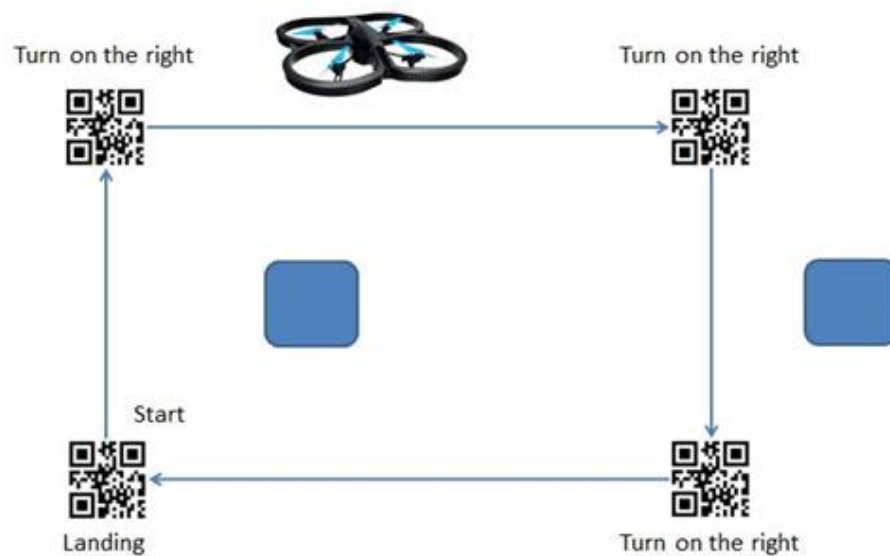


Figure 44: A visual representation of the project execution carried out in a garage of the University Jaime I of Castellón.

5.1 Communication AR.Drone-Client

To communicate with potential clients, the drone creates a Wi-Fi wireless network in Ad-hoc mode with which the client can send commands and the AR.Drone may send information.

The AR.Drone use a Wi-Fi b / g / n network, by allowing a range of about 50 meters can communicate with the client steady. Therefore, all communication that takes place between the client and the AR.Drone is through this network, so any client with access to the Wi-Fi network can contact him.

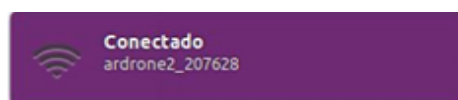


Figure 45: The Wi-Fi connection between client-AR.Drone 2.0

5.2 Running the application node-ar-drone-pilot

The aim of our application is to make the drone fly over a particular area completely autonomous, using the inertial navigation system and QR codes.

In figure 46 we can see the life cycle of the AR.Drone application. It refers to the different methods used. The first step is to run the application, and then the system is initialized, once initialized advances to find the first QR code. When located, the instructions contained in the QR code are executed. While not detect a QR code, the system executes the last instruction until it finds a QR code. The system ends when the instruction executed is landing. To restart the system must be initialized again.

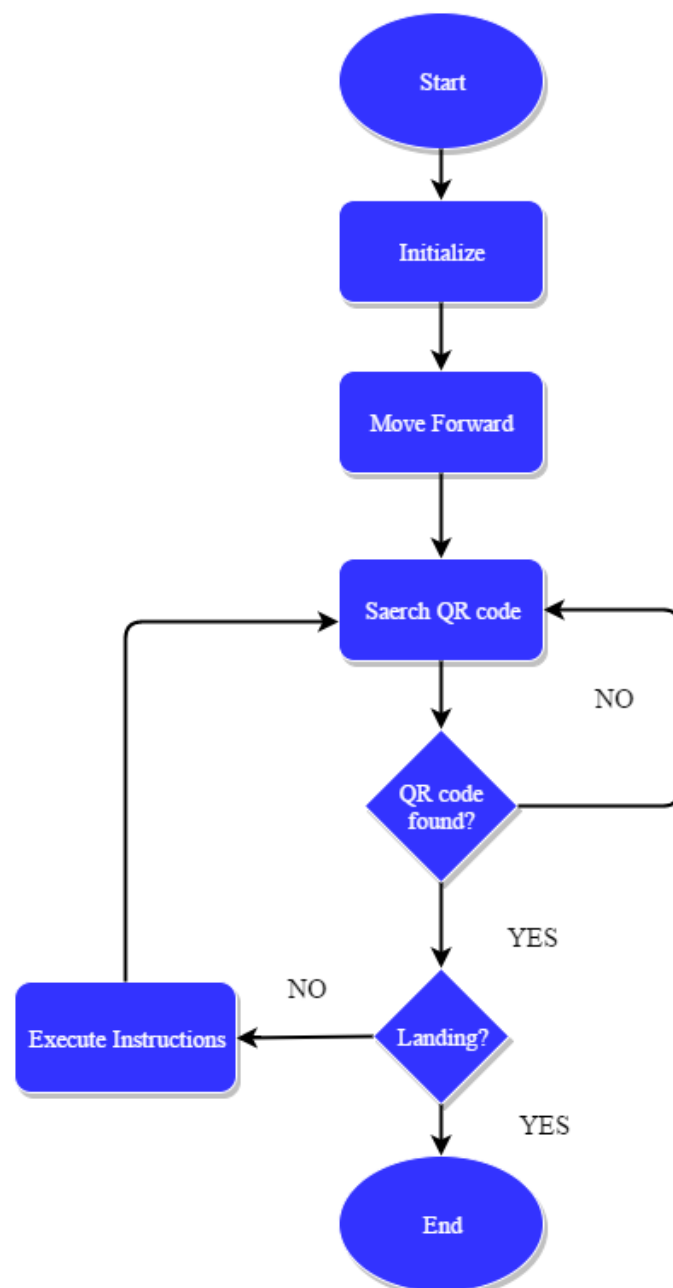


Figure 46: Sequence diagram of the application node-ar-drone-pilot.

Once connected to AR.Drone the next step is to run the application program. All the instructions decoded by drone-pilot.js are sending to repl.js that send the commands to the Ar.Drone.

```
emilio@emilio-VirtualBox:~/node-ar-drone-pilot$ node drone-pilot.js | node repl.js
```

Figure 47: drone-pilot.js execution.

After running the software we show a QR code to start the process. In this case, we use an iPad to show the QR code to the front camera. The instructions are take-off, calibrate the electronic compass, change bottom camera and go front at 0.035 m/s.

```
Client.createPngStream is deprecated. Use Client.getPngStream instead.  
takeoff()  
stop()  
calibrate(0)  
config("video:video_channel", 3)  
front(0.035)
```

Figure 48: Sequence of instructions to initialize the system. Takeoff, compass calibration and change the configuration to the bottom camera.

The next three steps are the same, turn on the right 90°, the AR.Drone must fly the boundaries of an area of 50 square meters.

```
stop()  
clockwise(0.5)  
stop()  
front(0.035)
```

Figure 49: Sequence of instructions to turn on the right 90° and continue straight.

And finally in the last instruction QR code is encoded landing

```
stop()  
land()
```

Figure 50: Sequence of instructions for landing.

5.3 Results

As a final result, our application allows using the AR.Drone 2.0 as a system controlled of autonomous flight through QR codes and the inertial navigation system. For this purpose, an application has been made for managing the operations of the AR.Drone 2.0. The test was conducted in an area of about 50 square meters. We have placed many QR codes on the ground. The test is to fly over the perimeter of a square area. This area is bounded on its four vertexes by QR codes. When the AR.Drone is flying over them and read it execute the instructions implemented in them.



Figure 51: Sequence of navigation in tests carried out in the garage of the University Jaime I of Castellón [53].

We have placed seven QR codes in each vertex as the inertial system that provides the AR.Drone is not very accurate and it is very difficult to make the AR.Drone without deviation follow a straight line. The seven QR codes contain the same information, the AR.Drone executes instructions of first QR code located. After completing the tests of our system and comparing it with others. We can obtain certain advantages and disadvantages. Within the disadvantages, we could say that the main disadvantage would be the accuracy. In advantages, we highlight the savings in infrastructure and system protection to jamming. In these tests, we have seen that the best high and the best linear speed to improve testing are about 1 meter high and 0.035 m / s linear speed.

TEST PARAMETERS	
Parameter	Value
Height	± 1 m
Speed	± 0.035 m/s
System accuracy	± 2 m

Table 3: Ideal parameters for the test obtained after different tests. In these tests, it was obtained an accuracy of 2 meters.

During these tests were obtained certain navdata and magnetometer data. These data are shown in section attachments.

6. CONCLUSIONS AND FUTURE WORK

Last but not least, in this chapter we present the conclusions which they are drawn from the realization of this Master's thesis, also some to make proposals for future work.

6.1 Conclusions

Reviewing the objectives for the realization of this Master's Thesis, then detailed the extent they have been met, besides conclusions is drawn in the process of carrying out the work:

- Research on the UAS has been important to know the operation thereof, the principles on which they are based and the variety of equipment in the world. First highlight the basic principles on which are based the quadcopters, allowing to know how the structure thereof, and the possible moves to be made and how they do it. This serves as a basis for understanding and meeting all necessary to perform movements and assess the status of the device variables. In addition, the UAS can be designed in many ways and with different sizes, allowing them to perform various tasks.
- This project has used the technique of location 'dead reckoning', which calculates the position of the UAS from the speed, direction, and time since the last known position time. We used proprioceptive sensors such as accelerometers and gyroscopes. The main problem with this approach is that each new position estimate includes a small error that accumulates over time. After a period of time sufficiently large, the position estimation so uncertain that would not be useful. However, despite the 'dead reckoning' long term is a method of insufficient location, it is a very useful mechanism in the short term if combined with external observations to correct the estimate. To avoid uncertainty in the position constantly increases, you cannot rely solely on incremental measures such as those provided by the proprioceptive sensors, but must incorporate exteroceptive sensors. In this case, the system is complemented using computer vision to read the QR codes that tell us besides the position navigation instructions to reach the destination. This makes it ideal for the development of industrial applications of closed loop system.
- There are many advantages of UASs in the industry than in the terrestrial robots. The speed and space are two of them. Unlike terrestrial robots, UASs can be moved in 3D, which saves space to different height levels used for the flight, so better use the space and gains in productivity.
- Focusing more on research regarding the operation of the AR Drone 2.0, we were obtained necessary knowledge about how to program a quadcopter and

basic elements that are essential for the development of one. As for the basic elements included the basis of a quadcopter own structure as well as the inertial navigation system and multiple sensors that provide measurements about the state of the drone and the environment and to make possible a stable flight.

- Regarding the development of the client, it has created an application in which all the functions offered by the AR.Drone have been merged into the application, allowing multitasks and get on different data. The functions to be performed by the application and detailed in the objectives are:
 - Perform efficient communication using the different commands accepted by AR.Drone, all via Wi-Fi.
 - Autonomous control of the AR.Drone by the different movements that can be performed, based on studies of the AR.Drone. For this, the software that allows such application is provided.
 - View the video captured by the cameras of the AR.Drone. Through these videos can be detected QR codes also view the environment by which the AR.Drone moves.
 - Obtaining and storing navigation data collected during the flight. This allows for analysis and treatment of post-flight data as well as the reconstruction of the flight using the stored movements.
- Tests conducted during the development of the application have been successful, so that all functions of the application work properly.

In conclusion, the proposed objectives for this Master's Thesis have been met, achieving a fully functional application that allows the AR.Drone flight completely autonomously.

6.2 Future Work

Based on the application made in this Master's Thesis to enable autonomous indoor navigation of AR. drone 2.0, there are several works that can be done and that will get more out of the profits of the AR.Drone. Some of the possible future works that may be performed include the following:

- Change INS and cameras on the AR.Drone by other higher quality for a more accurate navigation and high-quality observations.
- Provide the AR.Drone proximity sensors to avoid hitting persons or objects. Thus, it protects the environment and would be safer navigation.
- Create an application in which we can get the position of AR.Drone on a map in real time. It can be realized with the navigation data, information from the QR codes and images provided by the cameras.
- Using sensors that have the AR.Drone and some additional, we can know various environmental parameters of different locations and at different heights, and track them. Some of this data could be ambient temperature, atmospheric pressure, CO₂ levels, levels of electromagnetic signals, locating objects, the magnetic field strength, etc.
- Using this application and proposed improvements earlier in larger UAS could be made other applications using electromechanical actuators that enable systems to perform specific actions during autonomous navigation. Such as the installation of tweezers or electromechanical arms etc. This could carry boxes or pieces from one point to another, open doors etc. To control these electromechanical systems could use the same QR codes.

BIBLIOGRAPHIC REFERENCES

- [1] Sáez, F. J., & Portillo, Y. (2003). Descubrir la Navegación Aérea, (1ra). *Madrid–Spain: Aeropuertos Españoles y Navegación Aérea (Aena)*.
- [2] Riley, C., & Dolling, P (2009). NASA Apollo 11: Owners' Workshop Manual. Yeovil (Somerset)-UK: Haynes Publishing.
- [3] AR-Drone documentation. 2015. Information about AR-Drone of Parrot <http://ardrone2.parrot.com/> (accessed 23 November 2015).
- [4] Projects AR.Drone.2015. <https://projects.ardrone.org/> (accessed 23 November 2015)
- [5] Aerospace Control Laboratory (MIT).2015. <http://acl.mit.edu/> (accessed 25 November 2015)
- [6] Pierre-Jean Bristeau, François Callou, David Vissière, Nicolas Petit, 2011. The Navigation and Control technology inside the AR.Drone micro UAV.18th IFAC World Congress, pp. 1477-1484.
- [7] Hendrikus R. Oosterhuis and Arnoud Visser, 2013. Evaluation of tracking algorithms to autonomously following dynamic targets at low altitude.
- [8] AR-Drone SDK. 2015. <http://ardrone2.parrot.com/developer-zone/> (accessed 26 November 2015).
- [9] Node JavaScript. 2015. Information about a platform for building fast, scalable network applications. <https://nodejs.org/> (accessed 28 November 2015).
- [10] Bryson, M., & Sukkarieh, S. (2004, December). Vehicle model aided inertial navigation for a UAV using low-cost sensors. In Proceedings of the Australasian Conference on Robotics and Automation.
- [11] Li, B., Gallagher, T., Dempster, A. G., & Rigos, C. (2012, November). How feasible is the use of magnetic field alone for indoor positioning. In Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on (pp. 1-9). IEEE.
- [12] Engelbrecht, L., & Weinberg, A. (1996). U.S. Patent No. 5,510,801. Washington, DC: U.S. Patent and Trademark Office.

- [13] Moghtadaiee, V., Dempster, A. G., & Lim, S. (2011, September). Indoor localization using FM radio signals: A fingerprinting approach. In *Indoor Positioning and Indoor Navigation (IPIN), 2011 International Conference on* (pp. 1-7). IEEE.
- [14] Biswas, J., & Veloso, M. (2010, May). Wifi localization and navigation for autonomous indoor mobile robots. In *Robotics and Automation (ICRA), 2010 IEEE International Conference on* (pp. 4379-4384). IEEE.
- [15] Carrillo, D., Moreno, V., Úbeda, B., & Skarmeta, A. F. (2015). MagicFinger: 3D Magnetic Fingerprints for Indoor Location. *Sensors*, 15(7), 17168-17194.
- [16] Lowe, K. (2007). Distance estimation between transceivers over short distances (Doctoral dissertation, Clemson University).
- [17] Opoku, S. K. (2012). An Indoor Tracking System Based on Bluetooth Technology. arXiv preprint arXiv:1209.3053.
- [18] Gezici, S., Tian, Z., Giannakis, G. B., Kobayashi, H., Molisch, A. F., Poor, H. V., & Sahinoglu, Z. (2005). Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks. *Signal Processing Magazine, IEEE*, 22(4), 70-84.
- [19] Ni, L. M., Liu, Y., Lau, Y. C., & Patil, A. P. (2004). LANDMARC: indoor location sensing using active RFID. *Wireless networks*, 10(6), 701-710.
- [20] Marin-Garcia, I., Chavez-Burbano, P., Munoz-Arcentles, A., Calero-Bravo, V., & Perez-Jimenez, R. (2015, January). Indoor location technique based on visible light communications and ultrasound emitters. In *Consumer Electronics (ICCE), 2015 IEEE International Conference on* (pp. 297-298). IEEE.
- [21] Rida, M. E., Liu, F., Jadi, Y., Algawhari, A. A. A., & Askourih, A. (2015, April). Indoor location position based on Bluetooth Signal Strength. In *Information Science and Control Engineering (ICISCE), 2015 2nd International Conference on* (pp. 769-773). IEEE.
- [22] Hightower, J., Want, R., & Borriello, G. (2000). SpotON: An indoor 3D location sensing technology based on RF signal strength. UW CSE 00-02-02, University of Washington, Department of Computer Science and Engineering, Seattle, WA, 1.
- [23] Fukuju, Y., Minami, M., Morikawa, H., & Aoyama, T. (2003, May). DOLPHIN: An Autonomous Indoor Positioning System in Ubiquitous Computing Environment. In *WSTFEUS* (pp. 53-56).

- [24] Kirchner, N., & Furukawa, T. (2005, November). Infrared localization for indoor UAVs. In ICST05: Proceedings of the 2005 International Conference on Sensing Technology (pp. 60-65).
- [25] Zhang¹, C., Kuhn, M., Merkl, B., Fathy¹, A. E., & Mahfouz, M. Accuracy Enhancement of UWB Indoor Localization System via Arrangement of Base Stations.
- [26] Shi, G., & Ming, Y. (2016). Survey of Indoor Positioning Systems Based on Ultra-wideband (UWB) Technology. In Wireless Communications, Networking and Applications (pp. 1269-1278). Springer India.
- [27] Barshan, B., & Durrant-Whyte, H. F. (1995). Inertial navigation systems for mobile robots. *Robotics and Automation, IEEE Transactions on*, 11(3), 328-342.
- [28] Sinopoli, B., Micheli, M., Donato, G., & Koo, T. J. (2001). Vision based navigation for an unmanned aerial vehicle. In *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on* (Vol. 2, pp. 1757-1764). IEEE.
- [29] Woodman, O., & Harle, R. (2008, September). Pedestrian localisation for indoor environments. In *Proceedings of the 10th international conference on Ubiquitous computing* (pp. 114-123). ACM.
- [30] Baturone, A. O. (2005). *Robótica: manipuladores y robots móviles*. Marcombo.
- [31] Siciliano, B., & Khatib, O. (Eds.). (2008). *Springer handbook of robotics*. Springer Science & Business Media.
- [32] Aggarwal, P., Syed, Z., & El-Sheimy, N. (2014). *MEMS-based integrated navigation*. Artech House.
- [33] Shamsuzzoha, A. H. M., Ehlers, M., Addo-Tenkorang, R., Nguyen, D., & Helo, P. T. (2013). Performance evaluation of tracking and tracing for logistics operations. *International Journal of Shipping and Transport Logistics*, 5(1), 31-54.
- [34] TEC-IT 2D Barcode: QR-Code. <http://www.tec-it.com/en/support/knowledge/symbolologies/qr/Default.aspx> (accessed 12 December 2015).
- [35] Canadi, M., Höpken, W., & Fuchs, M. (2010). Application of QR codes in online travel distribution. *Information and Communication Technologies in Tourism 2010*, 137-148.

- [36] Stewart, L. E. (2010). QR codes: creative mobile media approaches (Doctoral dissertation, University of Texas).
- [37] Adsuar, J. C. (2007). Principios de vuelo. Editorial Paraninfo.
- [38] Parrot, «Introduction to quadrotor UAV» de AR Drone SDK 2.0 Developer Guide, pp. 5-7.
- [39] Parrot, «Incoming data streams» de AR Drone SDK 2.0 Developer Guide, pp. 39-41.
- [40] Parrot, «Incoming data streams» de AR Drone SDK 2.0 Developer Guide, pp. 43-58.
- [41] Parrot, « AR.Drone 2.0 SDK Overview» de AR Drone SDK 2.0 Developer Guide, pp. 13-17.
- [42] Devzone Parrot. <https://devzone.parrot.com/> (accessed 18 December 2015).
- [43] Paparazzi uav. http://wiki.paparazziuav.org/wiki/AR_Drone_2 (accessed 18 December 2015).
- [44] Ubuntu. <http://www.ubuntu.com/download/desktop> (accessed 20 December 2015).
- [45] Nodejs. <https://nodejs.org/en/> (accessed 20 December 2015).
- [46] Node ar-drone. <https://github.com/felixge/node-ar-drone> (accessed 21 December 2015).
- [47] Cairo library. <http://cairographics.org/> (accessed 21 December 2015).
- [48] FFmpeg. <http://ffmpeg.org/> (accessed 21 December 2015).
- [49] qrar package. <https://github.com/GraemeF/qrar> (accessed 22 December 2015).
- [50] drone-browser. <https://github.com/functino/drone-browser> (accessed 22 December 2015).
- [51] QR-Code. <http://www.codigo-qr.es/> (accessed 23 December 2015).
- [52] Raspberry Pi Zero, <https://www.raspberrypi.org/blog/raspberry-pi-zero/> (accessed 20 January)

- [53] Youtube, Test thesis. <https://youtu.be/fguQvTIC7hM> (accessed 21 January)
- [54] Agencia Estatal de Seguridad Aérea (AESA), Spain:
http://www.seguridadaerea.gob.es/lang_castellano/cias_empresas/trabajos/rpas/default.aspx (accessed 15 January)
- [55] European Aviation Safety Agency (EASA), Europe
<https://www.easa.europa.eu/regulations> (accessed 15 January)
- [56] International Civil Aviation Organization (ICAO), Worldwide
<http://www.icao.int/Pages/default.aspx> (accessed 15 January)
- [57] Eurocontrol, Europe <http://www.eurocontrol.int/rpas> (accessed 15 January)

ATTACHMENTS

A1 Navdata

In one minute and twenty seconds of flight, the system collects 1946 packets of Navdata

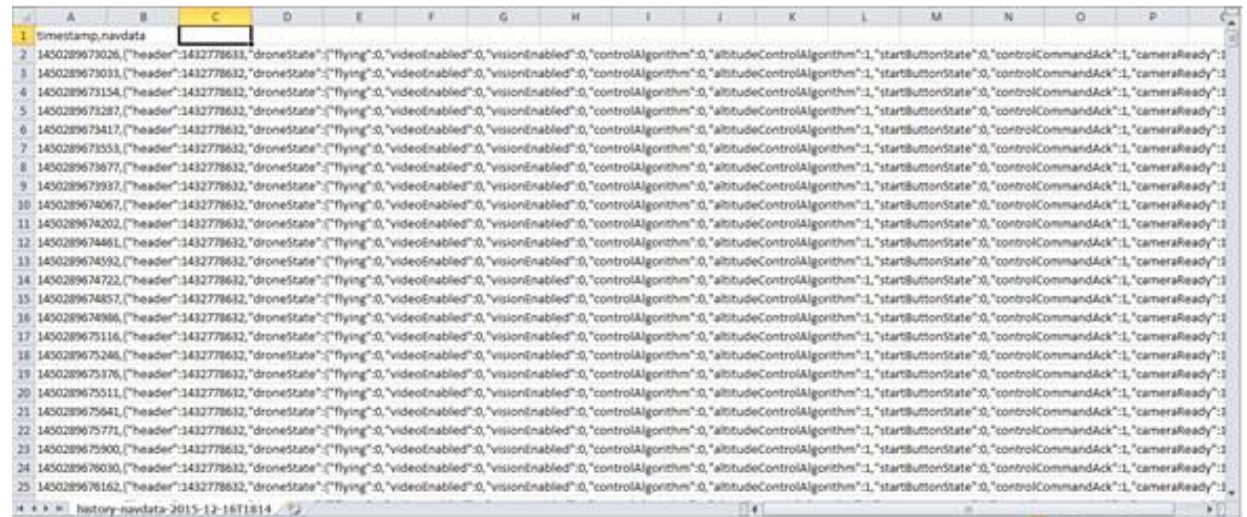


Table A-1: Navdata packets obtained from the UAS in one flight

This is one of the complete packets sent by the AR.Drone while was flying, we can see all the parameters on this timestamp of the flying:

```
1450289733750,{"header":1432778632,"droneState":{"flying":0,"videoEnabled":0,"visionEnabled":1,"controlAlgorithm":0,"altitudeControlAlgorithm":1,"startButtonState":0,"controlCommandAck":0,"cameraReady":1,"travellingEnabled":0,"usbReady":0,"navdataDemo":1,"navdataBootstrap":0,"motorProblem":0,"communicationLost":0,"softwareFault":0,"lowBattery":0,"userEmergencyLanding":0,"timerElapsed":0,"MagnetometerNeedsCalibration":0,"anglesOutOfRange":0,"tooMuchWind":0,"ultrasonicSensorDeaf":0,"cutoutDetected":0,"picVersionNumberOk":1,"atCodecThreadOn":1,"navdataThreadOn":1,"videoThreadOn":1,"acquisitionThreadOn":1,"controlWatchdogDelay":0,"adcWatchdogDelay":0,"communicationWatchdogProblem":0,"emergencyLanding":0},"sequenceNumber":2436,"visionFlag":1,"demo":{"controlState":"CTRL_LANDED","flyState":"FLYING_OK","batteryPercentage":26,"rotation":{"frontBack":-0.294,"pitch":-0.294,"theta":-0.294,"y":-0.294,"leftRight":-0.291,"roll":-0.291,"phi":-0.291,"x":-0.291,"clockwise":-70.295,"yaw":-70.295,"psi":-70.295,"z":-70.295},"frontBackDegrees":-0.294,"leftRightDegrees":-0.291,"clockwiseDegrees":-70.295,"altitude":0,"altitudeMeters":0,"velocity":{"x":0,"y":0,"z":0},"xVelocity":0,"yVelocity":0,"zVelocity":0,"frameIndex":0,"detection":{"camera":{"rotation":{"m11":0,"m12":0,"m13":0,"m21":0,"m22":0,"m23":0,"m31":0,"m32":0,"m33":0},"translation":{"x":0,"y":0,"z":0},"type":3},"tagIndex":0},"drone":{"camera":{"rotation":{"m11":0.09093332290649414,"m12":-0.9958417415618896,"m13":-0.005526917986571789,"m21":0.9958438873291016,"m22":0.09095931053161621,"m23":-0.004651619121432304,"m31":0.005135001614689827,"m32":-0.00508095882833004,"m33":0.9999738931655884},"translation":{"x":-0.8381903767585754,"y":0.20404237508773804,"z":-
```

238}}}, "visionDetect": {"nbDetected":0, "type": [0,0,0,0], "xc": [0,0,0,0], "yc": [0,0,0,0], "width": [0,0,0,0], "height": [0,0,0,0], "dist": [0,0,0,0], "orientationAngle": [0,0,0,0], "rotation": [{"m11":0, "m12":0, "m13":0, "m21":0, "m22":0, "m23":0, "m31":0, "m32":0, "m33":0}, {"m11":0, "m12":0, "m13":0, "m21":0, "m22":0, "m23":0, "m31":0, "m32":0, "m33":0}, {"m11":0, "m12":0, "m13":0, "m21":0, "m22":0, "m23":0, "m31":0, "m32":0, "m33":0}, {"m11":0, "m12":0, "m13":0, "m21":0, "m22":0, "m23":0, "m31":0, "m32":0, "m33":0}], "translation": [{"x":0, "y":0, "z":0}, {"x":0, "y":0, "z":0}, {"x":0, "y":0, "z":0}, {"x":0, "y":0, "z":0}], "cameraSource": [0,0,0,0]}

A2 Magnetometer Data

In this case, we show a table with the parameters in raw and in degrees of the magnetometer of three axes.

	A	B	C	D	E	F	G
1	time	mx	my	mz	rawx	rawy	rawz
2	1450289480118	-71	101	-19	-337.32421875	237.9609375	65.90625
3	1450289480262	-83	103	-17	-344.00390625	278.1796875	58.96875
4	1450289480377	-79	105	-13	-350.68359375	264.7734375	45.09375
5	1450289480509	-82	102	-16	-340.6640625	274.828125	55.5
6	1450289480637	-85	103	-13	-344.00390625	284.8828125	45.09375
7	1450289480779	-83	101	-19	-337.32421875	278.1796875	65.90625
8	1450289481032	-159	-73	-47	243.80859375	532.8984375	163.03125
9	1450289481168	-134	-160	-54	534.375	449.109375	187.3125
10	1450289481291	-127	-159	-67	531.03515625	425.6484375	232.40625
11	1450289481426	-134	-166	-60	554.4140625	449.109375	208.125
12	1450289481560	-133	-163	-61	544.39453125	445.7578125	211.59375
13	1450289481687	-127	-165	-65	551.07421875	425.6484375	225.46875
14	1450289481822	-135	-173	-61	577.79296875	452.4609375	211.59375
15	1450289481947	-126	-174	-64	581.1328125	422.296875	222
16	1450289482076	-41	-199	-89	664.62890625	137.4140625	308.71875
17	1450289482206	102	-178	-94	594.4921875	-341.859375	326.0625
18	1450289482337	193	-125	-71	417.48046875	-646.8515625	246.28125
19	1450289482467	222	-30	-46	100.1953125	-744.046875	159.5625
20	1450289482595	222	16	-30	-53.4375	-744.046875	104.0625
21	1450289482732	222	12	-30	-40.078125	-744.046875	104.0625
22	1450289482860	226	18	-32	-60.1171875	-757.453125	111
23	1450289482930	221	17	-33	-56.77734375	-740.6953125	114.46875
24	1450289483056	224	18	-24	-60.1171875	-750.75	83.25
25	1450289483185	224	18	-22	-60.1171875	-750.75	76.3125
26	1450289483314	226	16	-24	-53.4375	-757.453125	83.25
27	1450289483449	198	42	-30	-140.2734375	-663.609375	104.0625
28	1450289483579	131	101	-23	-337.32421875	439.0546875	79.78125

Table A-2: Magnetometer data obtained from the UAS in one flight

Masters Program in **Geospatial Technologies**



A Prospective Geoinformatic Approach to Indoor Navigation for Unmanned Air System (UAS) by use of Quick Response (QR) codes

Emilio Troncho Jordán

Dissertation submitted in partial fulfilment of the requirements
for the Degree of *Master of Science in Geospatial Technologies*

2016

A Prospective Geoinformatic Approach to Indoor Navigation for Unmanned Air System (UAS) by use of QR codes

Emilio Troncho Jordán





Masters Program in **Geospatial Technologies**



Supported by:



Education and Culture
ERASMUS MUNDUS